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THE FLORIDA STATE UNIVERSITY

COLLEGE OF ARTS AND SCIENCES

# A MESOSCALE STUDY OF SEA BREEZE ENHANCED SUMMER THUNDERSTORMS IN THE FLORIDA PANHANDLE

By

DAVID G. BIGGAR

A thesis submitted to the

Department of Meteorology

in partial fulfillment of the

requirements for the degree of

Master of Science

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**A MESOSCALE STUDY OF SEA BREEZE ENHANCED SUMMER THUNDERSTORMS IN THE FLORIDA PANHANDLE**

David G. Biggar, M.S.
The Florida State University, 1992
Major Professor: Henry E. Fuelberg, Ph. D.

The pre-convective environments of summer thunderstorms over the Florida panhandle have been investigated using ground based and remotely sensed data. One kilometer half-hourly Geostationary Operational Environmental Satellite (GOES) imagery centered over the Florida panhandle was recorded on a near daily basis on a high quality video recorder. Upper air data at 1200 UTC also were archived for the Florida panhandle. The data were collected during the summers of 1990 and 1991. During the research period, a total of 115 days had both usable satellite imagery and upper air data. Days were classified as "disturbed" or "non-disturbed" using the imagery. The "non-disturbed" days were further categorized as having "strong", "weak", or "no" convection. Composite sounding profiles of various meteorological parameters were constructed for each category of the non-disturbed days. Various stability indices were also calculated each day.

The best thermodynamic parameters for forecasting north Florida convection included mid-tropospheric moisture (particularly 700 to 500 mb) and low level instability. The best stability index for predicting convective

development was the Surface based Lifted Index (SLI).

Wind direction also was related to the degree of convective activity in the Florida panhandle. The strong convection days tended to have low level wind flow from more of a southerly and westerly direction. The driest days were more likely to have low level winds with northerly and easterly components.

# 1. Introduction.

## *a. Background*

The state of Florida has the largest concentration of thunderstorm activity of any state in the nation (Lutgens and Tarbuck 1989). Locations in the Florida panhandle have about 80 days with thunderstorms per year (Fig. 1). Most of these thunderstorms occur in the summer season during afternoon and early evening hours. Tallahassee, Florida has an average of 66 thunderstorm days from May to September according to climatological records. Much research into thunderstorm development over Florida has been done during the past 40 years. The majority of these studies, however, has been conducted in central and south Florida.

Three basic atmospheric ingredients are required for a thunderstorm to develop. The first ingredient is that significant low level moisture must be present. Water vapor in the atmosphere creates a reservoir of energy that provides the fuel to produce thunderstorm activity. The atmosphere must also be unstable. This instability occurs when air parcels are positively buoyant as they start to rise. Finally, the required upward motion can occur due to a variety of causes. Lifting over Florida in the summer is frequently caused by sea breeze induced convergence. This convergence combines with the thermally induced lift from daytime heating to produce convective activity.

Past thunderstorm research for Florida has considered the ingredients that cause convective activity. Researchers have studied the development of

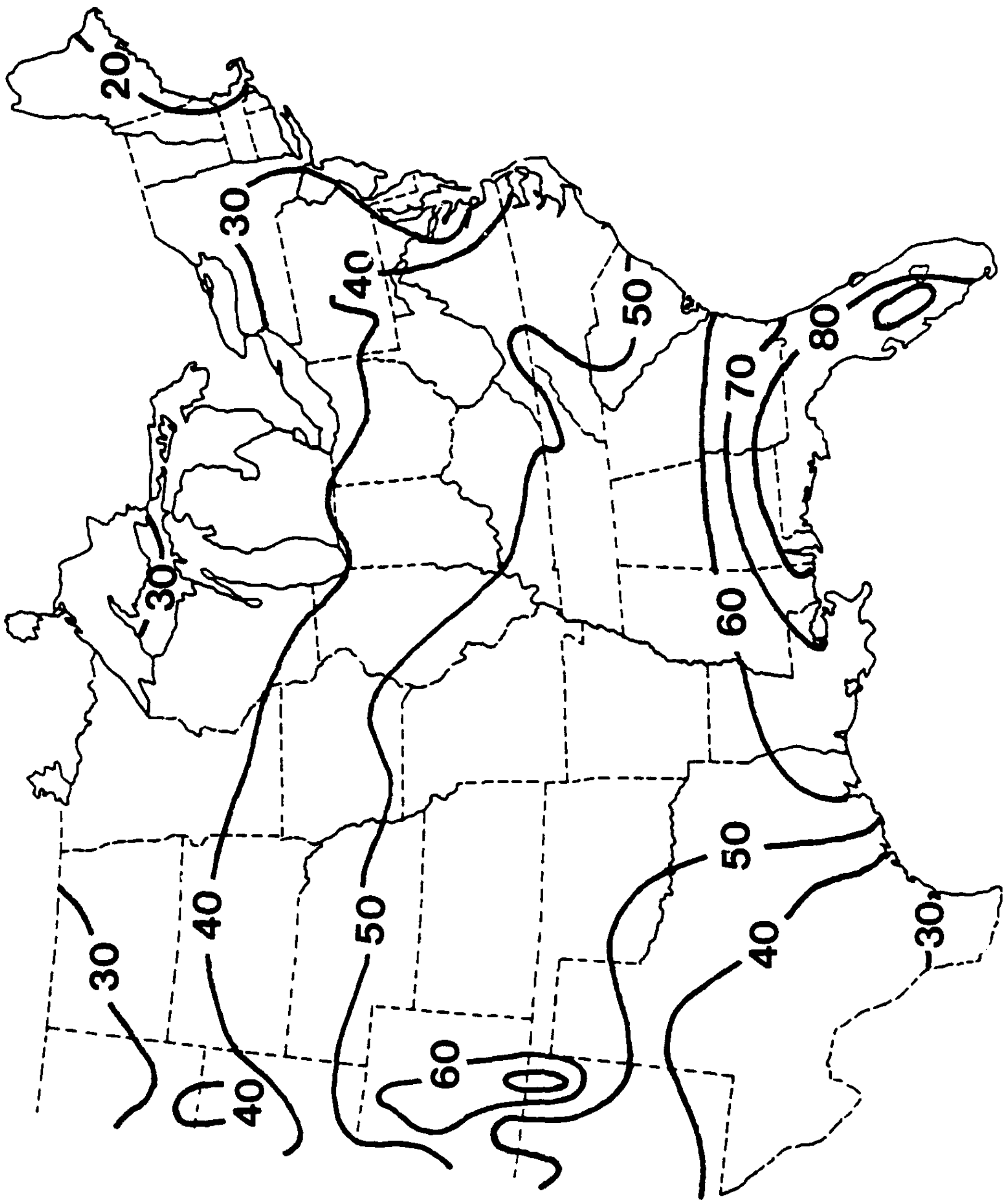



Fig. 1. Distribution of the average number of thunderstorms per year in the United States (After Lutgens and Tarbuck, 1989).

thunderstorms in relation to wind direction and speed, convergence of the wind, and thermodynamic parameters such as low level moisture and stability indices. Gentry and Moore (1954) used a network of rain gages to study the diurnal and spatial variation of showers near the southeast Florida coast and their relationship to the general wind speed and direction. Their technique allowed forecasters to more accurately determine which areas were most likely to receive showers and the time of most likely development. The diurnal and spatial variation of convective activity was also studied by Frank et al. (1967), who used manually recorded radar data in south Florida to determine the most likely time and location of shower activity. Pielke (1974) developed an 8-level, three dimensional, primitive equation model to describe the initiation and evolution of sea breeze induced convection over south Florida. Pielke's model investigated differences in the patterns of thunderstorm development under different wind regimes. The model results compared well with actual radar data. A recent study by Watson et al. (1991) studied lightning data in central Florida to look for preferential areas of thunderstorm development for various categories of low level wind flow. Lightning occurrences were most frequent during low level southwest flow and least frequent when the flow was from a northeasterly direction.

Several studies have considered relationships between convergence (generally sea breeze induced) and thunderstorm development in Florida. Byers and Rodebush (1948) noted that past research had indicated that the occurrence or nonoccurrence of thunderstorms could not be determined by purely thermodynamic considerations. They suggested that convergence resulting from coastal sea breezes was the dominant dynamic cause of the nearly daily thunderstorm activity in the Florida peninsula. Six-hourly

soundings were plotted for Jacksonville, Tampa, and Miami. Convergence was calculated in the lowest 5000 ft of the atmosphere. The peak convergence was found to occur at around 1600 EDT and extend up to around 3000 ft. A similar study done in a region bounded by Tallahassee, Montgomery, and Pensacola showed weaker and shallower convergence over the northern Gulf Coast. The smaller convergence is probably attributable to the northern Gulf Coast having no "double sea breeze" effect.

Wind and rain gage data from the Florida Area Cumulus Experiment (FACE) were analyzed by Ulanski and Garstang (1978), Cooper et al. (1982), and Watson and Blanchard (1984). A common finding from all of these studies was that the average time between the beginning of convergence and maximum rain was about 90 min. However, there were large standard deviations in the time of rainfall occurrence. Watson and Blanchard noted that the average time from the beginning of the convergence event to the beginning of rain was about 35 min. Ulanski and Garstang found that one of the most crucial factors in determining total rainfall was the areal coverage of the convergence.

Many studies of thunderstorm development over central and south Florida have considered the role of various thermodynamic parameters. Gentry (1950) stated that more accurate and specific forecasts than the usual "partly cloudy with scattered showers" could be made for Florida by considering moisture, instability, and large scale convergence. Radar data were used by Frank and Smith (1968) to study the correlation between echo area coverage and a number of meteorological parameters extracted from radiosonde observations. Their best correlation was with 650 mb humidity. A statistical predictor equation was derived by Neumann and Nicholson (1972) for

forecasting thunderstorms in the Cape Canaveral area of Florida. Their equation used 850 and 500 mb wind components, mean 800 - 600 mb relative humidity, the Showalter Stability Index (SSI), and the day number. Burpee (1979) used rain gage network data to show that there was very little difference between the magnitude of surface convergence on dry and wet sea breeze days. Variations in sea breeze forcing did not explain large differences in daily averaged rainfall that occurred in the summer. He found large differences between the mid-tropospheric moisture (and to a lesser extent temperature) profiles of dry and rainy sea breeze days. The lightning research project by Watson et al. (1991) also found mid-level moisture (particularly between 700 and 500 mb) to be an important factor in thunderstorm development. Lopez et al. (1984) stratified radar data from FACE according to degree of convective activity and then prepared mean soundings and typical synoptic maps. They also calculated multiple linear correlations between various thermodynamic parameters to study their predictive ability. They concluded that a large amount of the day to day variability in convective activity could not be explained by using a single early morning sounding. Watson and Blanchard (1984) calculated that the weakest low level wind was associated with the heaviest rainfall. They also found the SSI to be ineffective in South Florida although the K Index was somewhat useful.

Little published research is available on thunderstorms in north Florida. Smith (1970) collected digitized radar data at Apalachicola in the north Florida panhandle during the months of June, July, and August for the years 1965-67. He overlaid a 26 x 26 grid of 7.5 n mi squares over the PPI radar scope at 3-h intervals. Any squares which contained a radar echo were checked. Using this method, the radar operator could ignore non-meteorological features such as

anomalous propagation. However, no distinction was made concerning echo intensity. The observations were restricted to the summer months in order to exclude synoptic scale rainfall systems from the data. Most echo distributions observed during the summer months were found to be influenced by mesoscale and larger wind systems.

Smith (1970) used wind measurements obtained from pilot balloon (PIBAL) observations at three levels of the atmosphere over Tallahassee. These measurements were made at 1000, 3000, and 5000 ft. He determined the mean wind at these levels and postulated that the mean flow over Tallahassee was indicative of the mean flow over the panhandle region. This mean wind was categorized in quadrants as northerly, easterly, southerly, or westerly. However, when the mean speed was less than 5 kt, the wind was denoted as "light or variable". The winds were measured four times a day. If the wind category was the same for at least three of the observations, the day was categorized as having that direction. If the same category did not occur at least three times during the day, that day was also classified as light or variable. One problem with Smith's stratification scheme was that about 20% of the light and variable cases were contaminated by days that had insufficient data. Many of these days had cloudy and rainy weather that caused the measurement balloon to get lost in the clouds. A large number of these cloudy, rainy days with missing data probably had a southerly component.

Smith (1970) discussed the timing and location of the average radar echo distributions under the various wind regimes. He showed that variations in the shape of the coastline in north Florida affected typical locations of convective development. More recently, Purdom (1976) used satellite imagery to show the effect of coastline shape on convective development. Smith's north

Florida thunderstorm research was useful in depicting the average or typical locations of convective development for the predominant wind flow. However, it did not consider the thermodynamic factors that can affect the frequency of shower activity.

*b. Objectives*

The purpose of this research was to conduct a forecast study of summer thunderstorms over the Florida panhandle that are primarily caused by sea breeze induced convergence. These efforts were part of the Cooperative program for Operational Meteorology, Education and Training (COMET) between the Florida State University Department of Meteorology and the Tallahassee National Weather Service office. The study utilized 1 km high resolution visible satellite imagery to examine thunderstorm formation. An example of this imagery is shown in Fig. 2. The extent of thunderstorm development was compared with daily thermodynamic and wind parameters determined from upper air soundings. The results were compared with previous studies over Florida. With the exception of the aforementioned research by Smith (1970), all previously published Florida thunderstorm studies were conducted in the central or southern parts of the state. A major intent of my research was to improve the understanding of thunderstorm development in the panhandle region of Florida. The generally east to west orientation of the coastline in north Florida and the closer proximity to the continental land mass of North America were expected to cause differences in the patterns of thunderstorm development compared to the Florida peninsula.

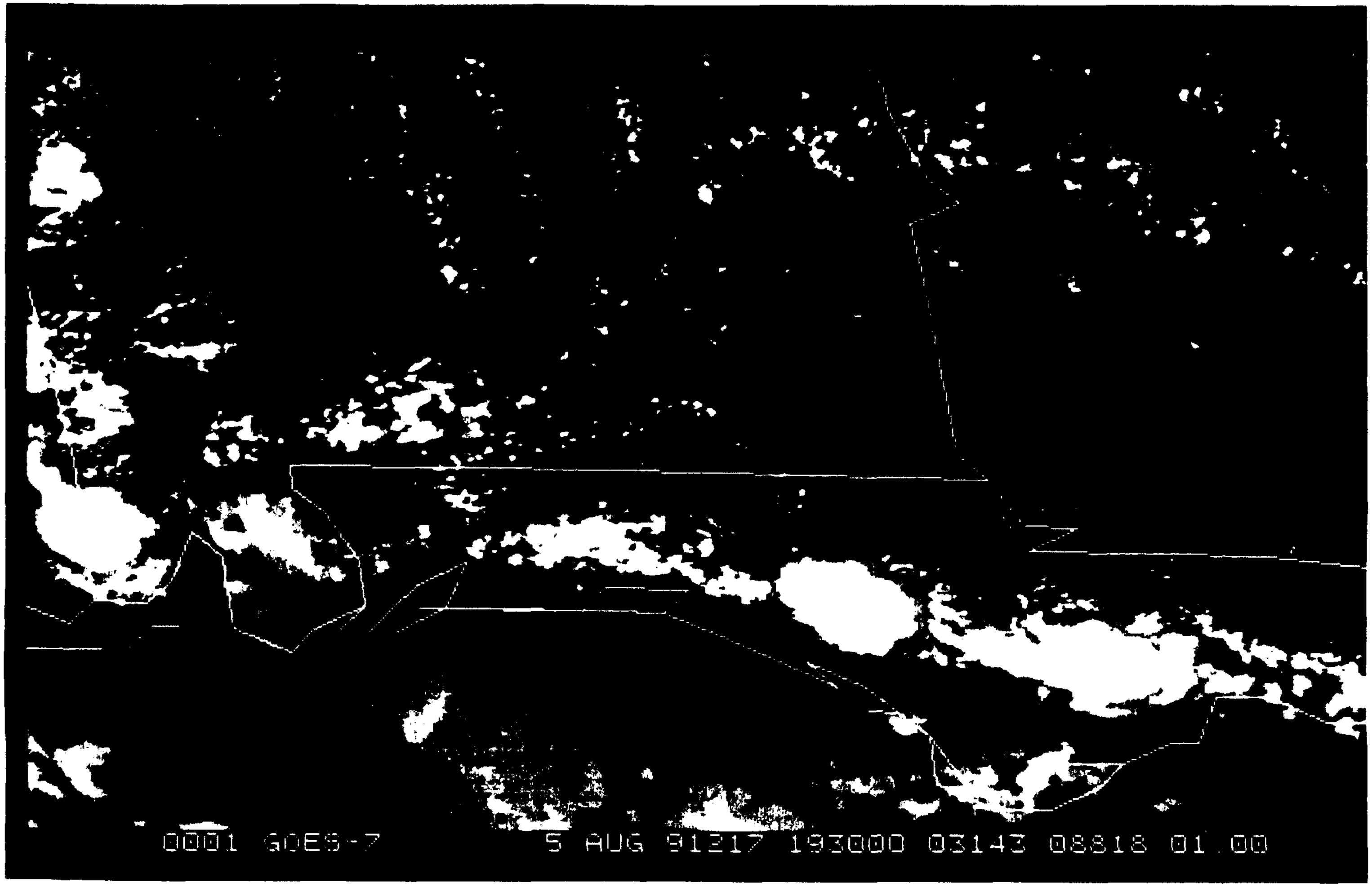



Fig. 2. GOES 1 km high resolution visible imagery for 1930 UTC 5 August 1991. Imagery shows example of a strong convection case.

## 2. Methodology.

Unlike previous studies of Florida thunderstorms that employed radar and/or rain gage networks, this research project used 1 km high resolution Geostationary Operational Environmental Satellite (GOES) satellite imagery at half hourly intervals. Although radar data would have been a useful supplement to the satellite imagery, the vivid detail of the high resolution imagery is relatively easy for the trained eye to interpret, and the cloud signatures of convective activity are easily distinguishable. In Fig. 2, for example, clouds are oriented along a line inland from the coast. This line of clouds represents the sea breeze front, defined as the line of convergence at the landward limit of the sea breeze penetration. This line of convergence forms convective clouds which are clearly visible on the satellite imagery. The larger cloud developments along the sea breeze front (Fig. 2) are the best developed thunderstorms. The satellite imagery used for this research project was centered over the panhandle region of north Florida. The boundaries for the forecast study (Fig. 3) were a subset of the image area. The east to west midpoint was over Apalachicola (AQQ), with the region stretching about 150 km to the west and east of AQQ and northward to the Alabama and Georgia borders. The eastern edge of the study area was near Tallahassee (TLH), and the western edge was near Panama City, Florida (PAM).

In addition to the satellite imagery, upper air data within the region were used to study the thermodynamics and wind conditions. The sounding site of

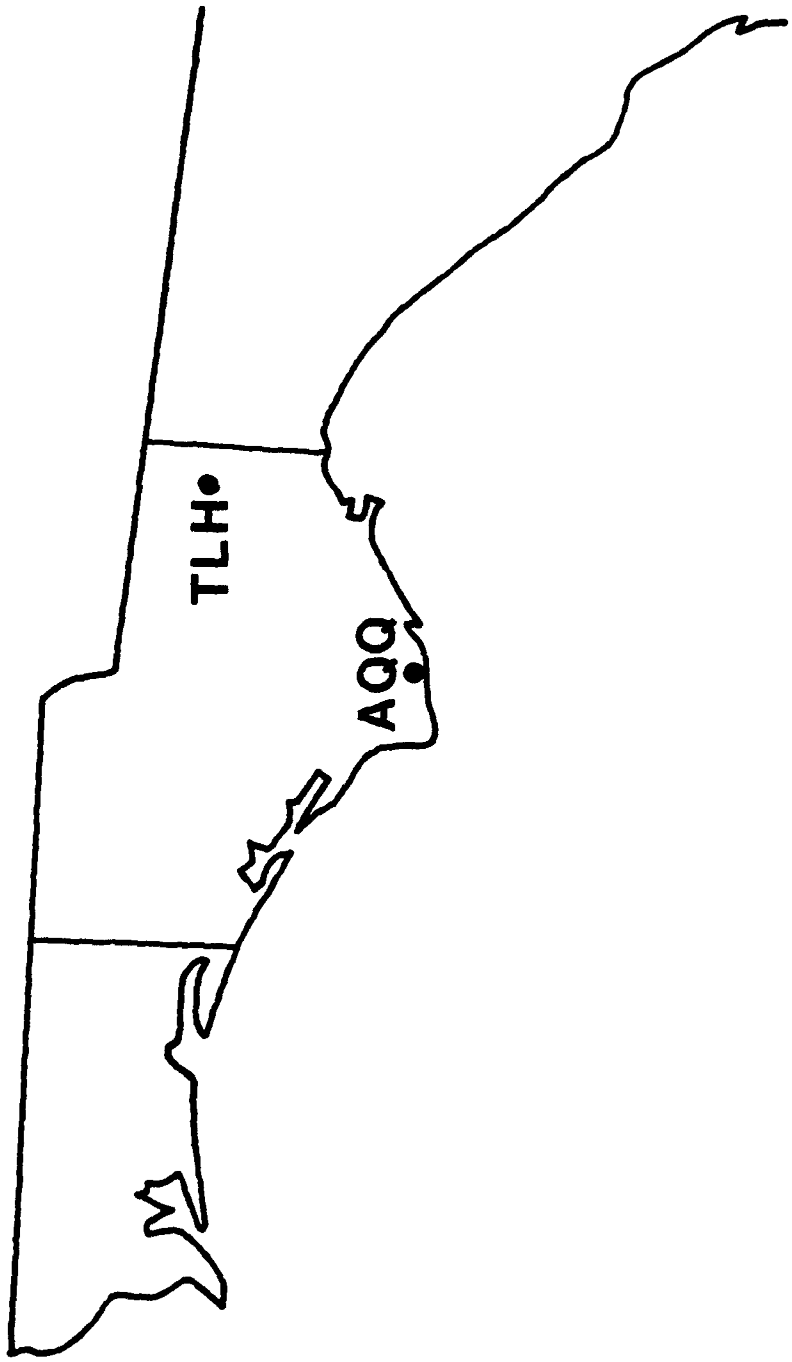



Fig. 3. Map of Florida panhandle showing the region used for classifying convection. TLH and AQQ represent Tallahassee and Apalachicola, respectively.

AQQ was used until 12 June 1991 when it was moved about 100 km east-northeastward to TLH. This site was also located within the region of study. Although it would have been preferable for the sounding site to have remained at the same location, the move did not seem to cause any major problems for this research project.

The research was conducted during the summers of 1990 and 1991. The study period for the first summer was delayed slightly due to equipment problems after the satellite receiving system was installed. During the summer of 1990, high resolution visible satellite imagery over north Florida was recorded on a near daily basis on a high quality video recorder. Data were not recorded during certain week-ends, and when equipment problems were experienced. During the time period that the satellite imagery was being recorded, upper air soundings at 1200 UTC for Apalachicola were archived into computer files . The first date of usable satellite data for 1990 was on 26 June. The data were collected through 16 September 1990. After this date the air became drier and less summerlike with the passage of a cold front. A total of 66 days out of a possible 83 days during 1990 had both usable satellite imagery and upper air data.

The data collection in 1991 commenced at the beginning of the summer weather season on 16 May. The collection period ended on 31 August. The satellite imagery of the Florida panhandle area was again recorded on a video recorder. In addition, the 1991 imagery was also archived onto a magneto optical disc. Some equipment problems were experienced in May, but most of the summer had good image collection. One minor problem occurred in June when the upper air sounding site moved from Apalachicola to Tallahassee. Equipment failures after the move caused problems in the Tallahassee

sounding. Overall, the summer of 1991 had a total of 93 out of a possible 108 days with both good satellite imagery and 1200 UTC upper air data for north Florida.

After the imagery was collected, a four part classification system was devised based on areal coverage of cloudiness and convection. The first category, called "disturbed", was defined as a day that had significant low and/or high cloudiness (over 50% coverage) during the morning. This category had a total of 35 occurrences during the two summers. These days were omitted from the data pool. The main objective of this study was to learn more about summer sea breeze enhanced convection in north Florida on synoptically quiet days. However, many of the days with significant morning cloudiness were affected by either mid-latitude or tropical weather systems. Since days with morning cloudiness did not have normal solar heating of the land, strong sea breezes usually did not develop. Burpee (1979) made a similar distinction between disturbed and non-disturbed days in his study of south Florida convection. Burpee categorized disturbed days using an objective criterion, based on the observed opaque cloud amount included in the surface data observations. The current use of high resolution satellite data to categorize disturbed days is an easier and more accurate method.

The remainder of the days, classified as undisturbed, were separated into three categories: Strong Convection (SC), Weak Convection (WC), and No Convection (NC). Most days clearly fit into one of the categories but on some "borderline" days it was more difficult to determine the appropriate category. The "strong convection" group consisted of days when the largest thunderstorm cells within the area of interest (Fig. 3) had an area coverage greater than 500

$km^2$. The videotapes of satellite imagery were used to make this cell coverage determination. The example in Fig. 2 was classified as a strong convection case. This category was the norm rather than the exception during the two summers. Of the 115 total days that were classified as non-disturbed, 66 of them were considered to have strong convection.

The other extreme category for undisturbed conditions was "no convection". This condition was noted in the study region on 26 days. No convective rainshowers occurred within the boundaries of the study area during the afternoon hours of these days.

The final category for undisturbed conditions was the intermediate "weak convection" category. The weak convection days had one to five small cells, with the largest cell having an area less than 500 $km^2$. This group had a total of 23 days. This intermediate category was necessary because some days could not be justifiably placed in either of the other two extreme categories. They did not have enough convective development to be accurately called "strong convection" days. However, since one or several small cells developed in the area of interest, they also could not be classified as having no convection.

## 3. Results

Mean soundings of various meteorological parameters were constructed for the three non-disturbed categories. In addition, sounding differences were calculated between the individual categories and the average of all non-disturbed days. The differences were calculated for the temperature and dew point data. Average values for each non-disturbed category were calculated for relative humidity, wind speed, and u- and v-components of the wind.

Results of the temperature profiles (Fig. 4) are not very enlightening. Unlike the south Florida studies of Burpee (1979) and Lopez et al. (1984), there is minimal difference in temperature profiles between wet and dry days over north Florida. Burpee found that temperatures between 850 and 450 mb on the driest days were consistently warmer than the mean of all days. For this Florida panhandle study, however, average lapse rates of the three categories differ little from one another, although there is a slight lapse rate variation between the SC and NC categories from the 800 to 700 mb level. The possibility that caps (i.e., inversions) cause suppressed storm activity on certain days was considered by calculating the minimum lapse rate (at least 10 mb thick) between 950 and 650 mb on each 1200 UTC sounding. These minimum lapse rates were averaged for each of the three undisturbed categories. Results (not shown) indicate that the average minimum lapse rate within each category is not significantly different from the others. In summary, mean temperatures and

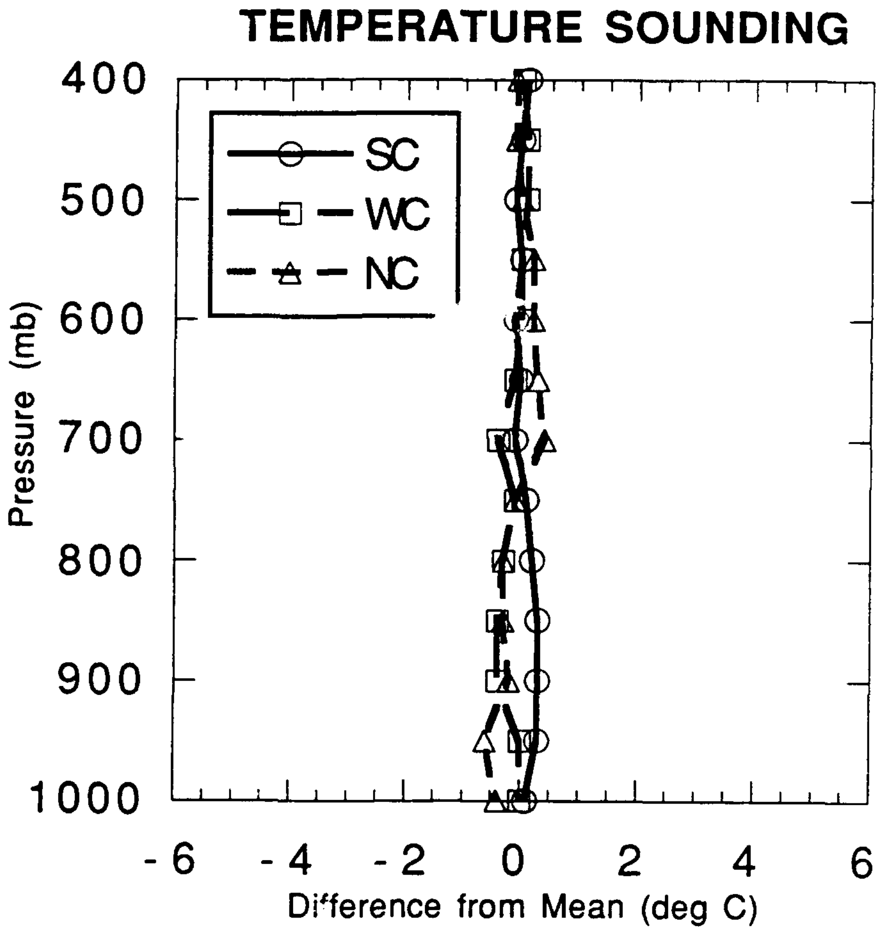



Fig. 4. Mean vertical profiles of temperature difference for each category. The three categories are Strong Convection (SC), Weak Convection (WC), and No Convection (NC).

lapse rates at 1200 UTC give little indication as to the likelihood for afternoon convection over the Florida panhandle.

The sounding profiles for mean dew point differences (Fig. 5) do yield interesting results. The no convection category is consistently drier at all levels than the other two categories. The average surface dew point difference of the weak convection category is nearly the same as that of the no convection category. However, above the surface, the intermediate weak convection category is actually moister than the strong convection category, especially above 600 mb. The largest overall difference (4 - 6 $^{o}C$) between the no convection and other categories occurs between 700 and 500 mb.

Moisture differences between categories are also evident in the average relative humidity profiles (Fig. 6). As in the dew point data, the most significant differences occur between 700 and 500 mb. Average relative humidity for the no convection category is approximately 20% smaller than the convection categories in this layer. Average relative humidities of the strong and weak convection days are very similar, ranging from about 85% near the surface to 40% at 400 mb. The finding that mid tropospheric moisture (especially between 700 and 500 mb) is an important parameter in determining the likelihood of convection agrees with conclusions by Watson et al. (1991). Their research showed that mid-level moisture (particularly 700 to 500 mb mean relative humidity) plays an important role in the development of convection over central Florida. This mid-level moisture factor is different from forecast parameters used in midwestern United States severe thunderstorm prediction where dry air aloft is often associated with severe weather. The 700 to 500 mb layer will be used in some of the discussions that follow.

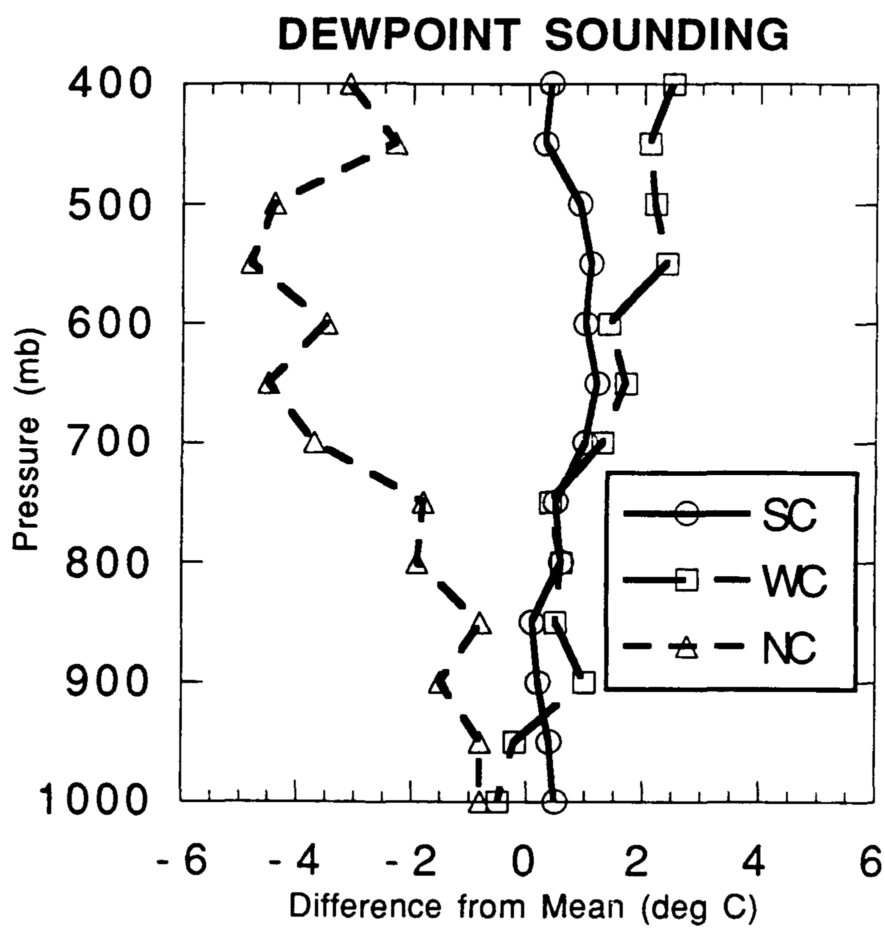



Fig. 5. As in Fig. 4, but mean vertical profiles of dew point difference for each category.

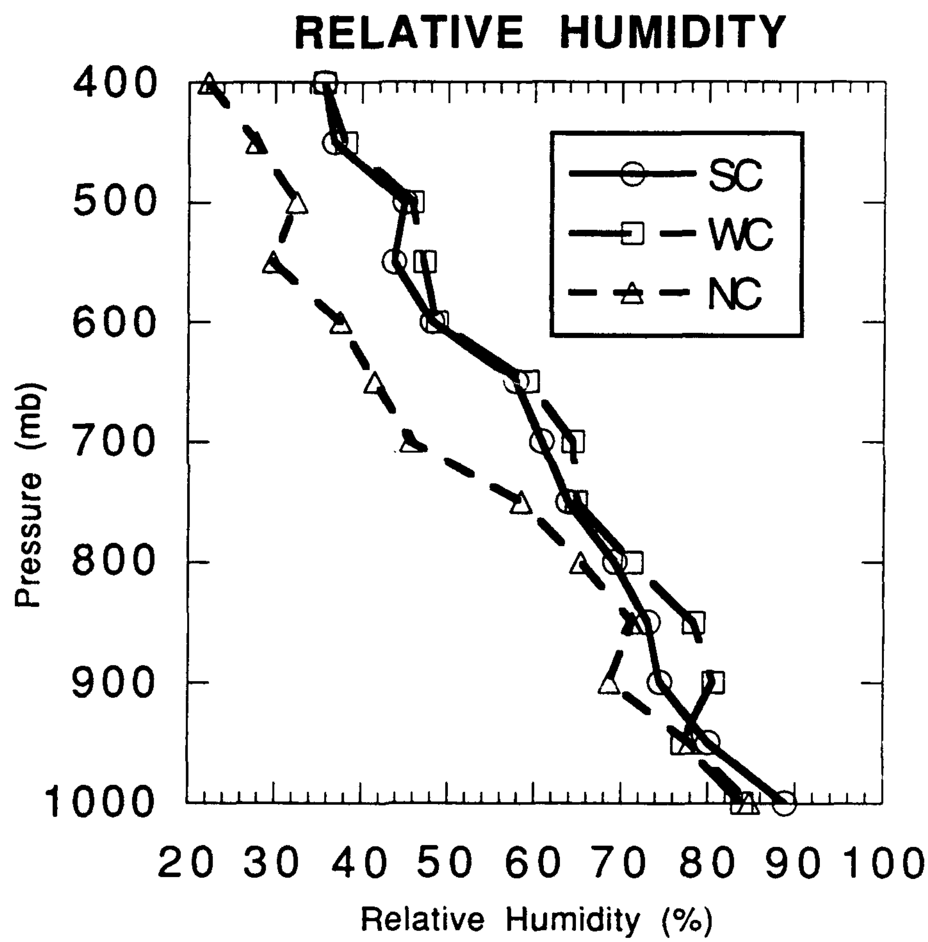



Fig. 6. As in Fig. 4, but mean vertical profiles of relative humidity for each category.

Wind speed and direction from 1000 to 400 mb were also studied. Speed differences among the categories are minor at most levels (Fig. 7). Average speeds between 1000 and 850 mb are lightest for the weak convection category. Average wind speeds for the strong convection and no convection categories are nearly identical in the lower levels. At 500 mb and above, average speeds are strongest for the no convection category. These results differ from those in south Florida. For example, Watson and Blanchard (1984) concluded that more intense convection occurred when the speeds were lighter.

To study the effects of the wind direction on storm formation, u and v wind components were calculated at each level for each category. Below 800 mb, the strong convection category has a significantly greater westerly (positive u) component than the other categories (Fig. 8). This result agrees with that of Smith (1970) who noted a significant suppression of shower activity in the Florida panhandle under an easterly wind regime.

Mean profiles for the v-component (Fig. 9) show that the no convection category has a northerly component at all levels. Conversely, the weak and strong convection categories tend to have southerly components at most levels. These results suggest that even though northerly components would cause greater convergence with the sea breeze front in the east / west oriented Florida panhandle, the dry continental air associated with northerly flow may tend to suppress convective activity.

Another way of considering the relationship between wind direction and the degree of convective activity is shown in Figs. 10, 11 and 12. The 850 mb level was chosen because directions at this level appear to be best correlated with the degree of daily convective activity (Figs. 8 and 9). Figure 10 gives the percentage of days for each category that had a southerly versus a northerly

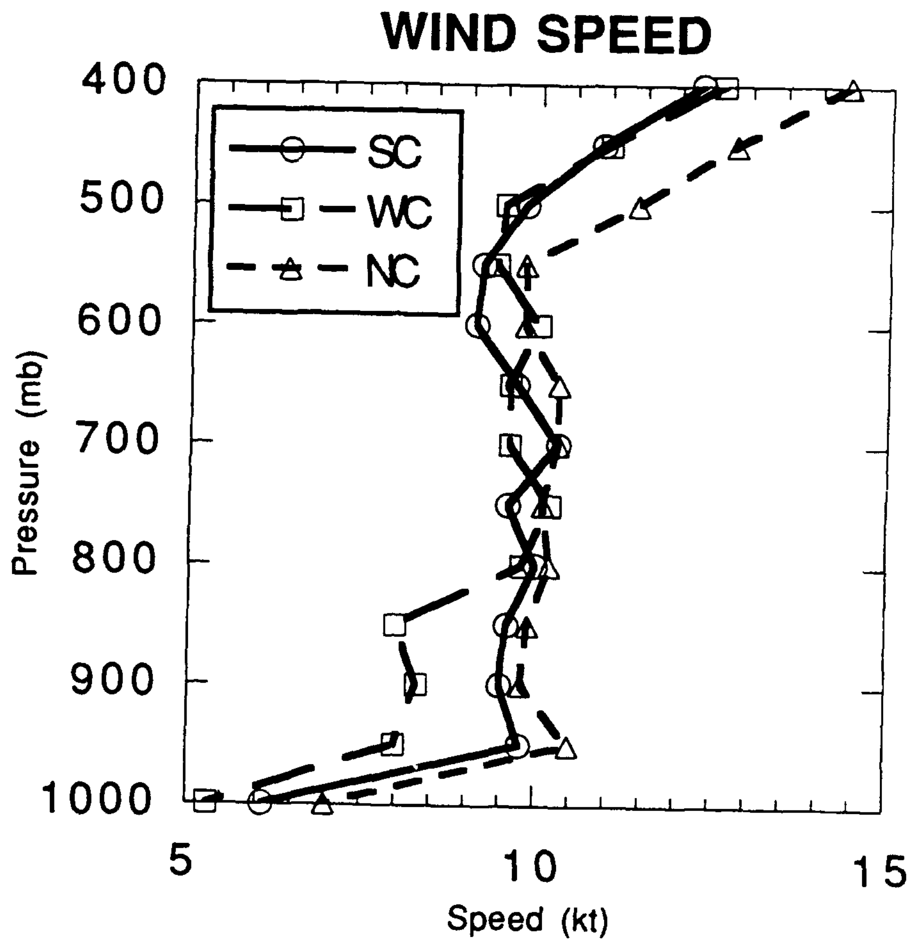



Fig. 7. As in Fig. 4, but mean vertical profiles of wind speed for each category.

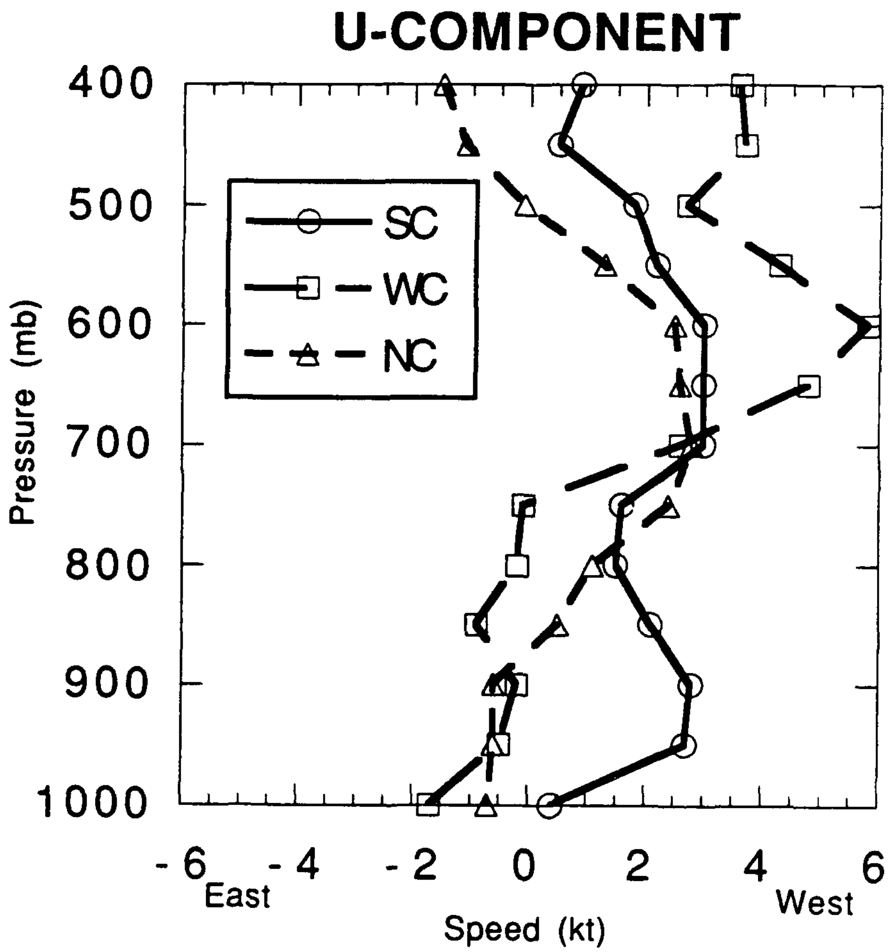



Fig. 8. As in Fig. 4, but mean vertical profiles of u-component for each category.

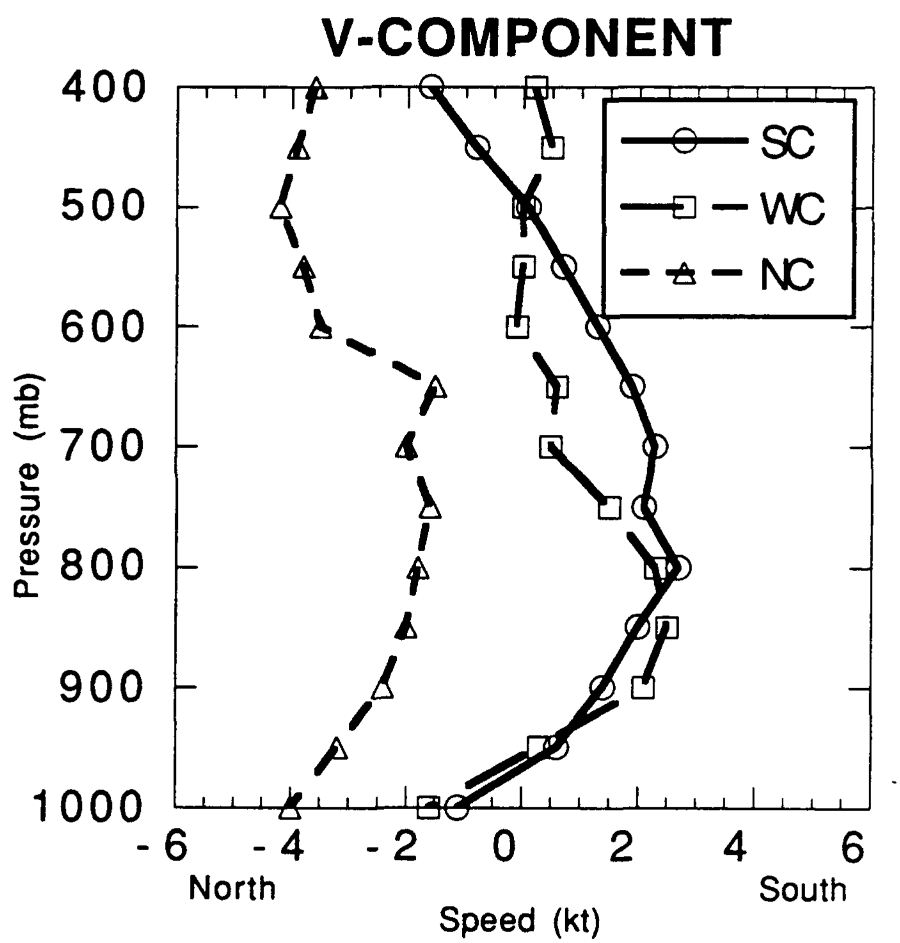



Fig. 9. As in Fig. 4, but mean vertical profiles of v-component for each category.

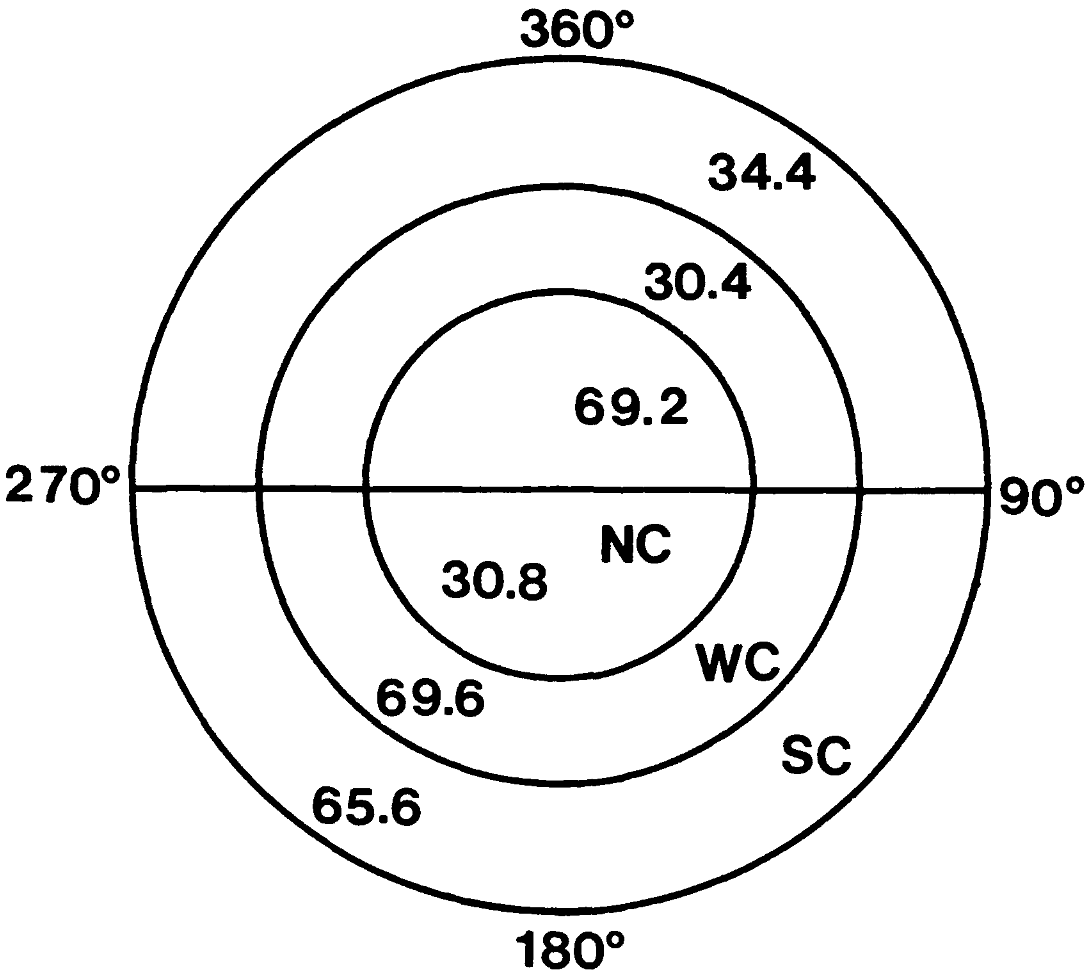



Fig. 10. Percentage of 850 mb wind cases having a northerly versus a southerly component. The inner circle represents the No Convection category (NC), the middle circle represents the Weak Convection category (WC), and the outer circle represents the Strong Convection Category (SC).

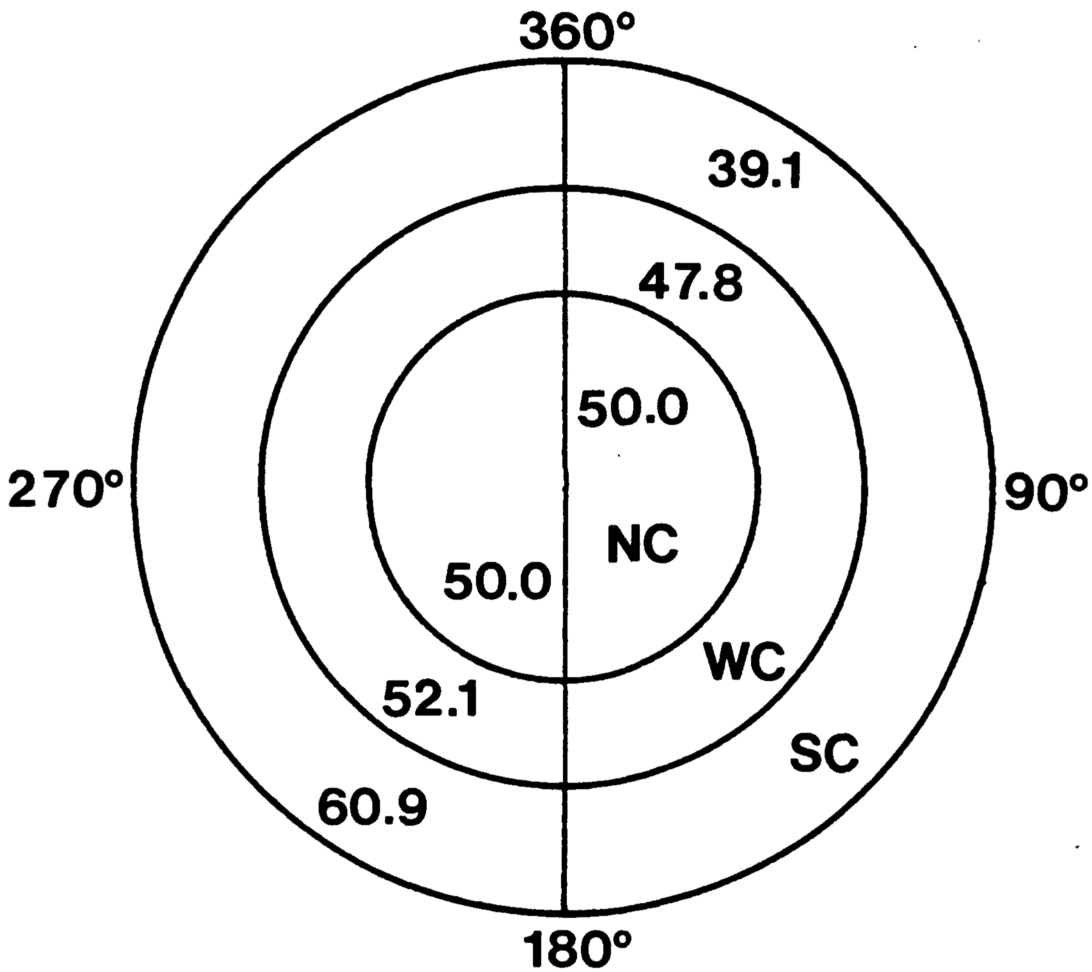



Fig. 11. As in Fig. 10, but percentage of 850 mb wind cases with a westerly versus easterly component for each category.

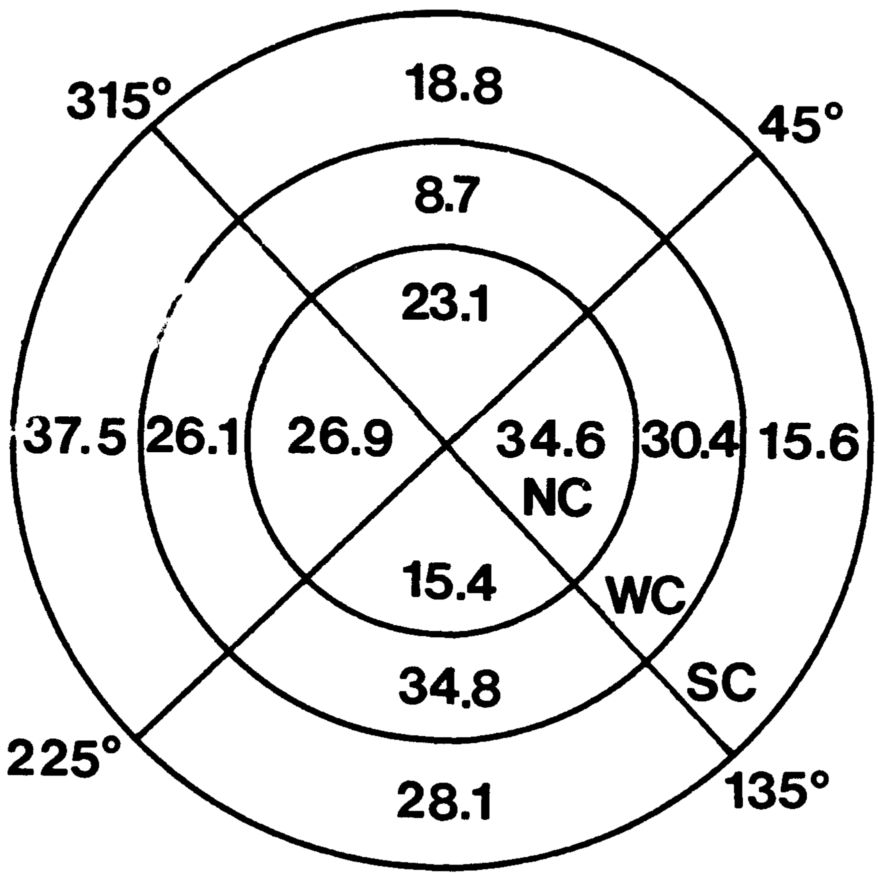



Fig. 12. As in Fig. 10, but percentage of 850 mb wind cases from the northerly, easterly, southerly, or westerly quadrant for each category.

component. The results show that 850 mb winds have a generally southerly component on 65.6% of the strong convection days. The weak convection days also show a tendency (69.6%) for a southerly component. On the other hand, the no convection days have a northerly component on 69.2% of the days. The percentage of days for each category having a westerly versus an easterly component is shown in Fig 11. The SC days have a westerly component on 60.9% of the days, with the other two categories less likely to have a westerly component. The NC days have a westerly component on 50% of the days. Figure 12 shows the percentage of days for each category having an 850 mb wind direction from the easterly, southerly, westerly, or northerly quadrants. The easterly quadrant is defined as 45 - 135$^{o}$, the southerly quadrant from 135 - 225$^{o}$, etc.. The SC days are less likely than the NC days to have an 850 mb wind from the easterly or northerly quadrants. The SC days most often have winds from the west (37.5%) or south (28.1%). On the other hand, the NC days rarely have an 850 mb wind from the southerly quadrant. Their flow is most often from the east (34.6%).

Various stability indices were calculated to determine which would work best in predicting convection in the Florida panhandle. This study considered the Total-Totals (TT) index, the Showalter Stability Index (SSI), the K Index (KI), the Lifted Index (LI), and the Surface based Lifted Index (SLI). Upper air data used in the calculations came from the morning (1200 UTC) soundings for Apalachicola or Tallahassee.

The formula for the Total Totals index (Miller 1972) is:

$$TT = (900\text{ mb T} + 900\text{ mb TD}) - (2 \times 500\text{ mb T}), \qquad (1)$$

where T is the temperature and TD is the dew point temperature, both in degrees Celsius. Median values for the TT index are nearly identical for each of the three categories (not shown). Other statistics of TT also show little difference between categories. Thus, the TT index is not a useful indicator for convection in the Florida panhandle during summer.

The remaining four stability indices exhibit varying degrees of success in predicting convective activity in north Florida. Bar graphs were plotted showing the number of times that a particular category of convection occurred for a specific range of stability values. Mean and median values were also calculated for each category. Later sections will examine the predictive success of each index using various statistical methods.

The K Index (KI) (George 1960) is a measure of thunderstorm potential based on the temperature lapse rate, the moisture content of the lower atmosphere, and the vertical extent of the moist layer. The following formula defines the K Index:

$$\begin{aligned} KI = {} & (850\text{ mb T} - 500\text{ mb T}) + (850\text{ mb TD}) \\ & - (700\text{ mb TDD}), \end{aligned} \tag{2}$$

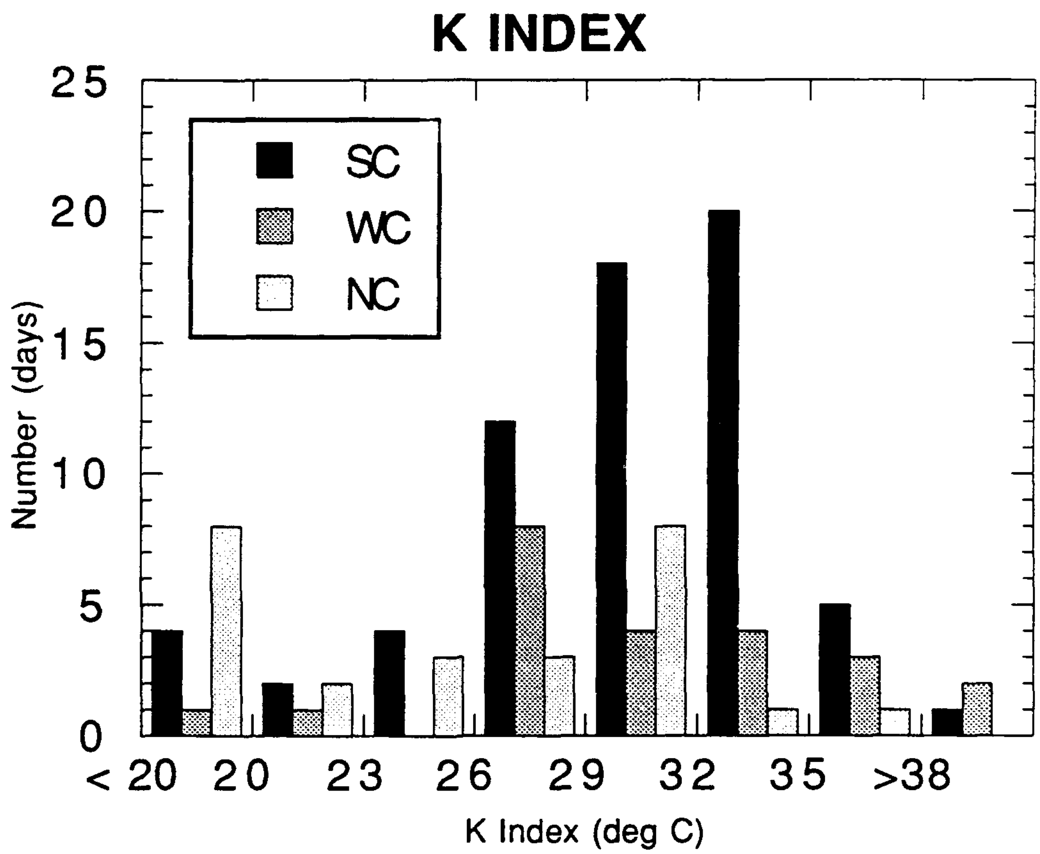
where TDD is the dew point depression in degrees Celsius. The KI is considered to be a useful index for predicting "air mass" thunderstorms which occur in areas of weak winds, away from synoptic scale frontal or cyclonic influence (Sadowski and Rieck 1977). They are the most common type of storm in north Florida during the summer. In general, a KI greater than or equal to 28 indicates a strong likelihood of convective activity.

For this north Florida study, the K Index is a reasonably good indicator in distinguishing convective from non-convective days (Fig. 13). Means and medians for these categories differ by 6.8 and 3.5 $^{o}$C, respectively. However, there is little differentiation between the strong and weak convection days since mean and median values are almost identical.

The Showalter Stability Index (SSI) (Showalter 1953) is a commonly used thunderstorm predictor. The SSI is computed by raising a parcel at 850 mb dry adiabatically until saturation. From this point, it is lifted moist adiabatically to the 500 mb level. The temperature of the parcel at 500 mb is subtracted from the observed 500 mb temperature. Sadowski and Rieck (1977) noted that negative values of SSI are associated with thunderstorm activity. Heavy thunderstorms are likely for values less than -3.

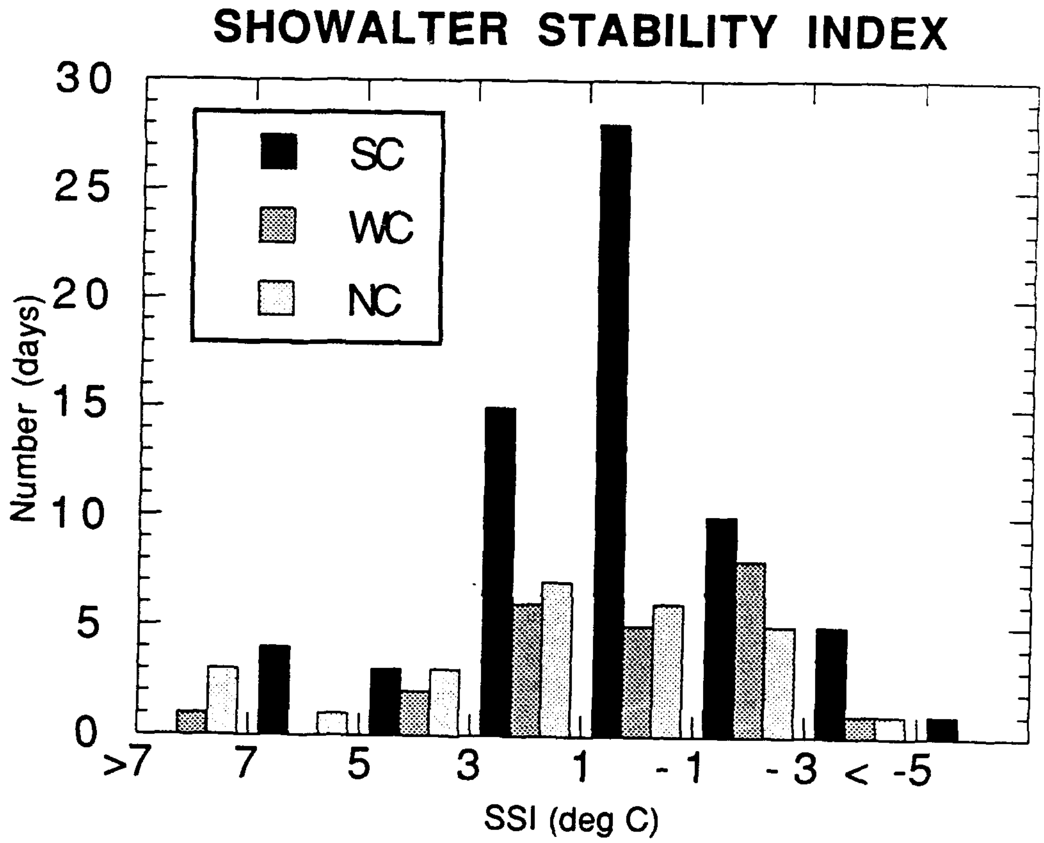
The current research shows that strong convective activity often occurs in the Florida panhandle with positive SSI (Fig. 14). Furthermore, there are only small differences (about 1 $^{o}$C) between mean and median SSI values of the three categories. These results agree with Watson and Blanchard (1984) who showed the SSI to be very ineffective as a predictive tool in Florida.

The Lifted Index (LI) (Galway 1956) was calculated at 1200 UTC using the mean temperature and dew point of the lowest 100 mb layer to represent the rising parcel. The mean parcel was lifted dry adiabatically from 50 mb above the surface to its saturation point, and then lifted moist adiabatically to 500 mb. The temperature of the parcel at 500 mb was subtracted from the observed 500 mb temperature to give the Lifted Index. The LI shows some value in differentiating between the three categories (Fig. 15). For example,



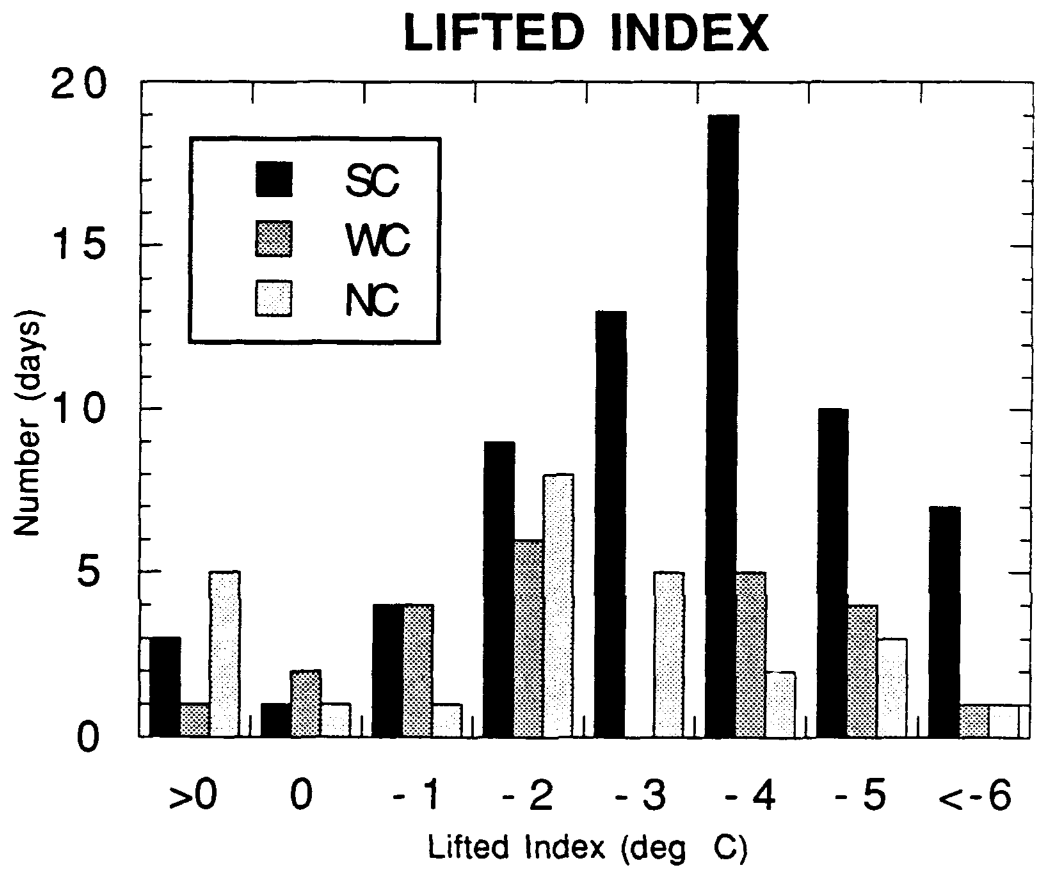

| CATEGORY | MEAN | MEDIAN |
|---|---|---|
| Strong Convection (SC) | 29.2 | 30.0 |
| Weak Convection (WC) | 29.4 | 31.0 |
| No Convection (NC) | 22.4 | 26.5 |

Fig. 13. Distribution of K Index values for each category. Mean and median values are also given.




| CATEGORY | MEAN | MEDIAN |
|---|---|---|
| Strong Convection (SC) | 0.41 | 0.40 |
| Weak Convection (WC) | 0.44 | -0.30 |
| No Convection (NC) | 1.68 | 1.40 |

Fig. 14. Distribution of Showalter Stability Index (SSI) for each category. Mean and median values are also given.



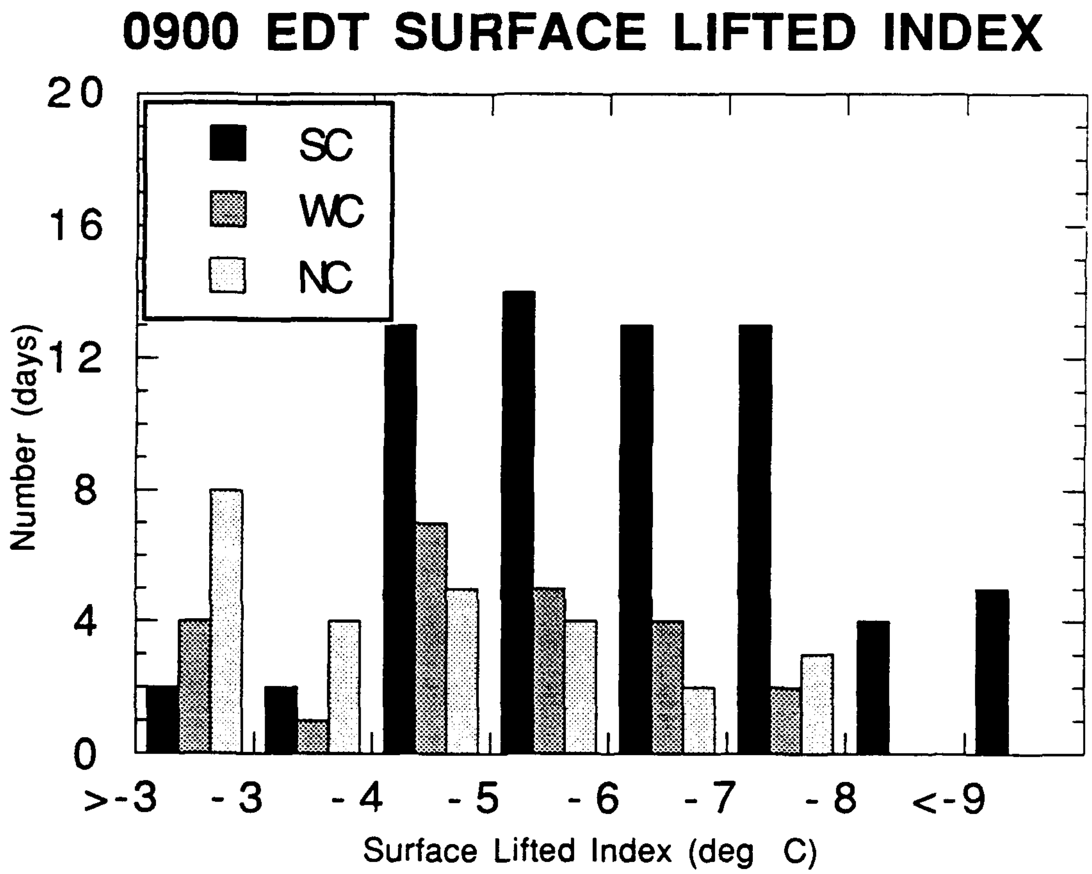

| CATEGORY | MEAN | MEDIAN |
|---|---|---|
| Strong Convection (SC) | -3.90 | -4.05 |
| Weak Convection (WC) | -3.00 | -2.80 |
| No Convection (NC) | -2.00 | -2.75 |

Fig. 15. Distribution of Lifted Index (LI) for each category. Mean and median values are also given.

mean and median values differ by 1.9 and 1.3 $^{O}C$, respectively, between the SC and NC categories.

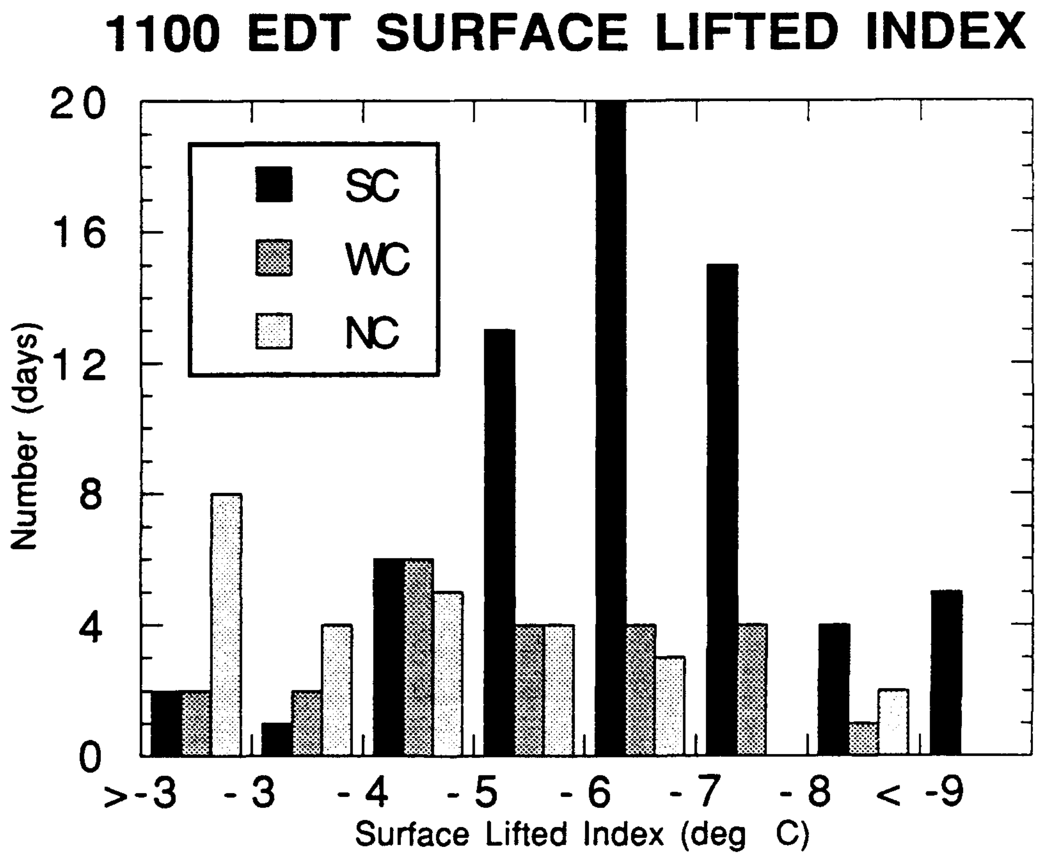
A variation to the Lifted Index, the Surface based Lifted Index (SLI) was also considered as a forecast tool. Hales and Doswell (1982) and Sanders (1986) stated that the SLI, which is based on the latest hourly surface temperature and dew point and the latest available 500 mb temperature, is a good indicator of the potential for convection at a particular location. The SLI can be more time and location specific than the traditional LI, which depends on layer averaged upper air data from sounding sites widely separated in both time and space. To compute the SLI, a surface parcel is lifted dry adiabatically to saturation, followed by moist adiabatic ascent to 500 mb. This procedure assumes that surface conditions represent those of the entire boundary layer. The parcel temperature at 500 mb is then subtracted from the observed 1200 UTC 500 mb temperature at the nearest upper air sounding (either TLH or AQQ). A 500 mb forecast temperature could have been used; however, this procedure was not employed since conditions at 500 mb usually vary little during short periods over North Florida during summer. Surface temperatures and dew points for Tallahassee were used to calculate the SLI. Tallahassee was chosen since it is the only panhandle station that is far enough inland so that surface temperatures and dew points are not strongly affected by the advancing sea breeze. Thus, the Tallahassee data were expected to be more representative of the general surface thermal and moisture situation.

Figure 16 shows the distributions and statistics of the SLI at 0900 EDT. The SLI was also calculated at 1100 EDT (Fig. 17). The 1100 EDT SLI is the latest that can be calculated for the afternoon forecast for a local National




| CATEGORY | MEAN | MEDIAN |
|---|---|---|
| Strong Convection (SC) | -6.1 | -6.25 |
| Weak Convection (WC) | -4.6 | -4.80 |
| No Convection (NC) | -3.5 | -4.05 |

Fig. 16. Distribution of 0900 EDT Surface based Lifted Index (SLI) for each category. Mean and median values are also given.




| CATEGORY | MEAN | MEDIAN |
|---|---|---|
| Strong Convection (SC) | -6.5 | -6.50 |
| Weak Convection (WC) | -5.2 | -5.40 |
| No Convection (NC) | -3.7 | -4.75 |

Fig. 17. Distribution of 1100 EDT Surface based Lifted Index (SLI) for each category. Mean and median values are also given.

Weather Service office and provides a good last minute look at the convective potential for the afternoon. Differences between mean SLI values of the SC and NC categories are greater at 1100 EDT (2.8 $^{o}$C) than at 0900 EDT (2.6 $^{o}$C). Conversely, median differences between the NC and SC categories are slightly smaller at 1100 EDT than at 0900 EDT. The statistical significance of these differences will be described later. These analyses will indicate that SLI is the best forecasting tool of the indices examined.

To determine whether the temperature or dew point was the most important factor in the SLI results, Tallahassee temperatures and dew points were averaged at hourly intervals for each category of days. During the morning, when the surface data were used for the SLI computations, the average temperatures vary little between categories (Fig. 18). The strong convection days are cooler during the afternoon hours due to the increased amount of cloudiness associated with the shower activity and due to evaporative cooling. There are significant differences in the mean morning dew points between the categories (Fig. 19). The dew points are approximately 2 $^{o}$C cooler throughout the days with no convection. Therefore, morning surface dew points are an indicator of convective potential in north Florida during the summer. The usefulness of surface dew points as an indicator of convective potential is demonstrated by the relative success of the SLI (which uses surface dew points and temperatures).

A scatter diagram containing 1100 EDT SLI versus the mean 700 to 500 mb relative humidity was plotted (Fig. 20). This layer had the greatest humidity difference between the strong and no convection categories (Fig. 6). Once again, only the two extreme categories are shown. This plot illustrates that the

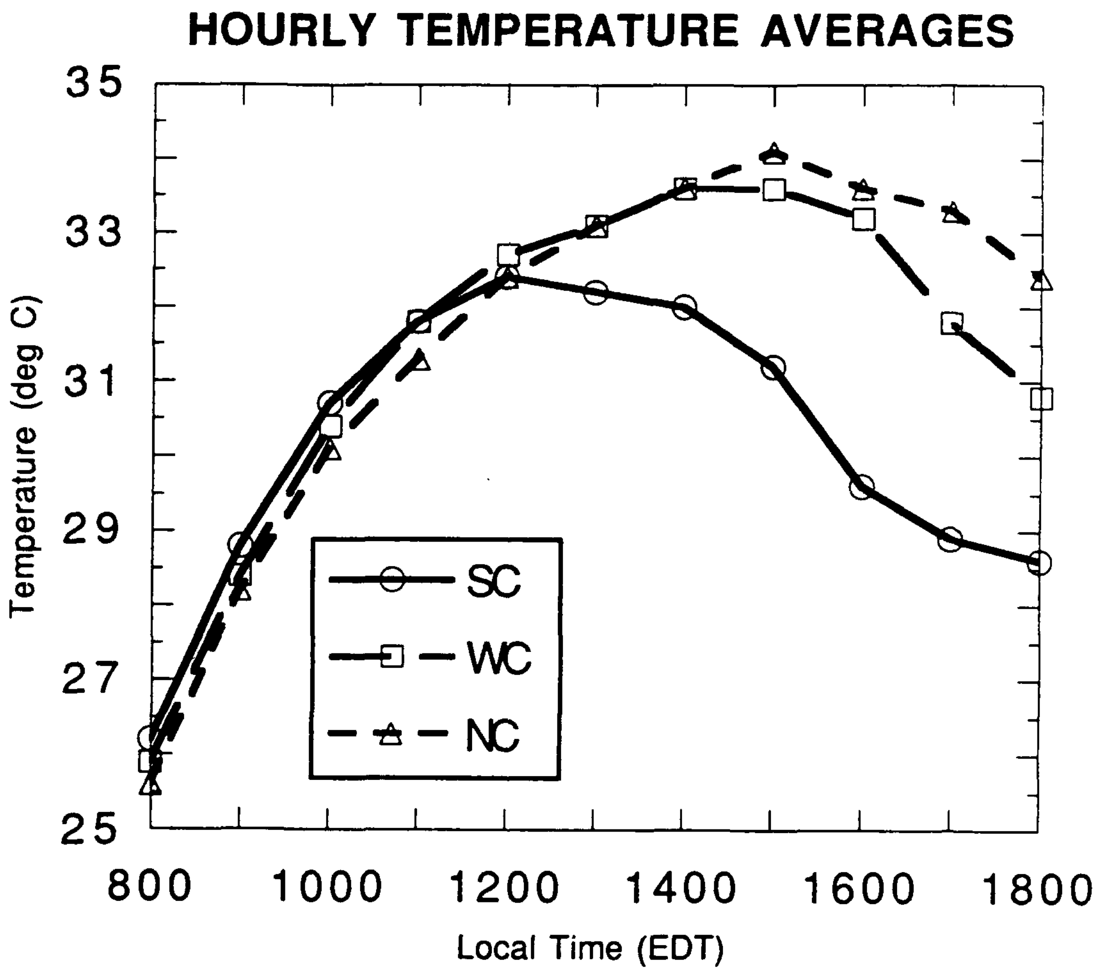



Fig. 18. Hourly temperature averages at Tallahassee from 0800 to 1800 EDT for each category.

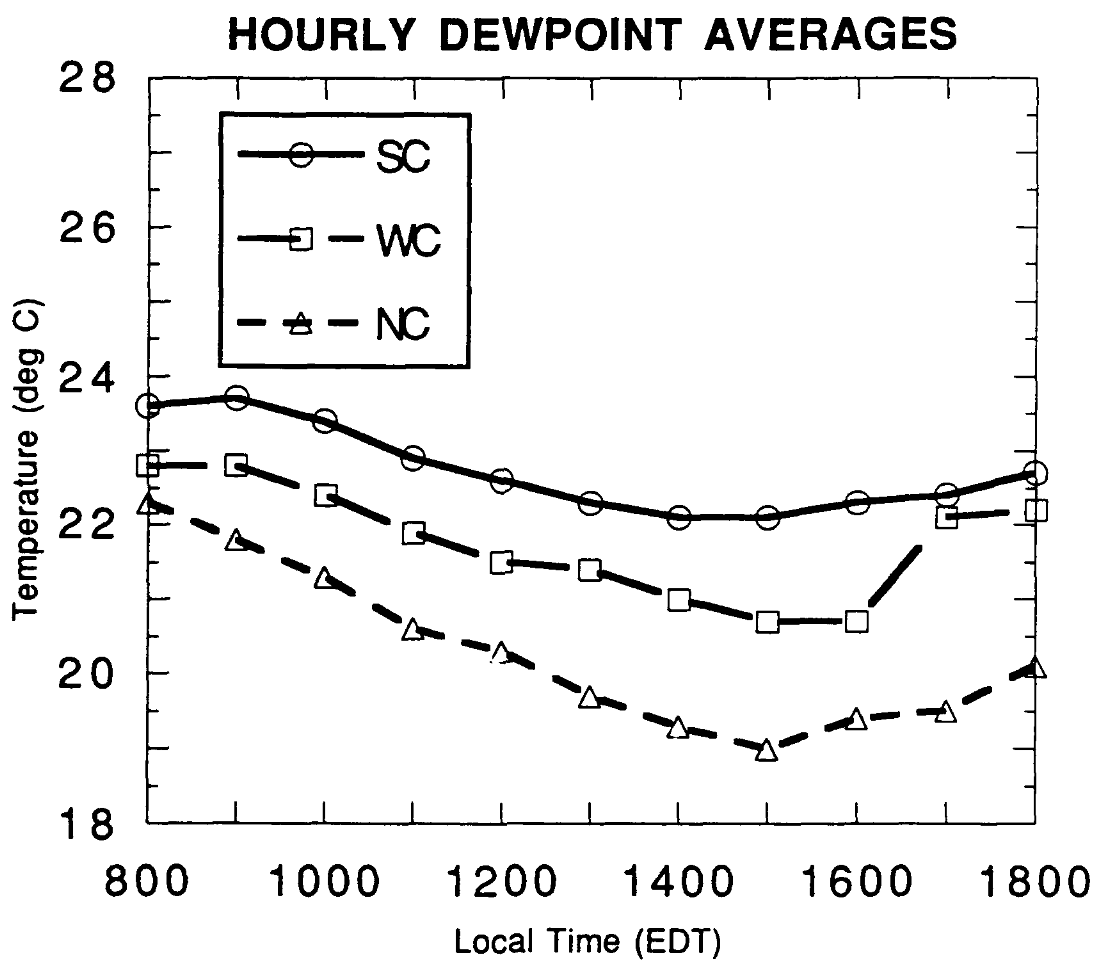



Fig. 19. Hourly dew point averages at Tallahassee from 0800 to 1800 EDT for each category.

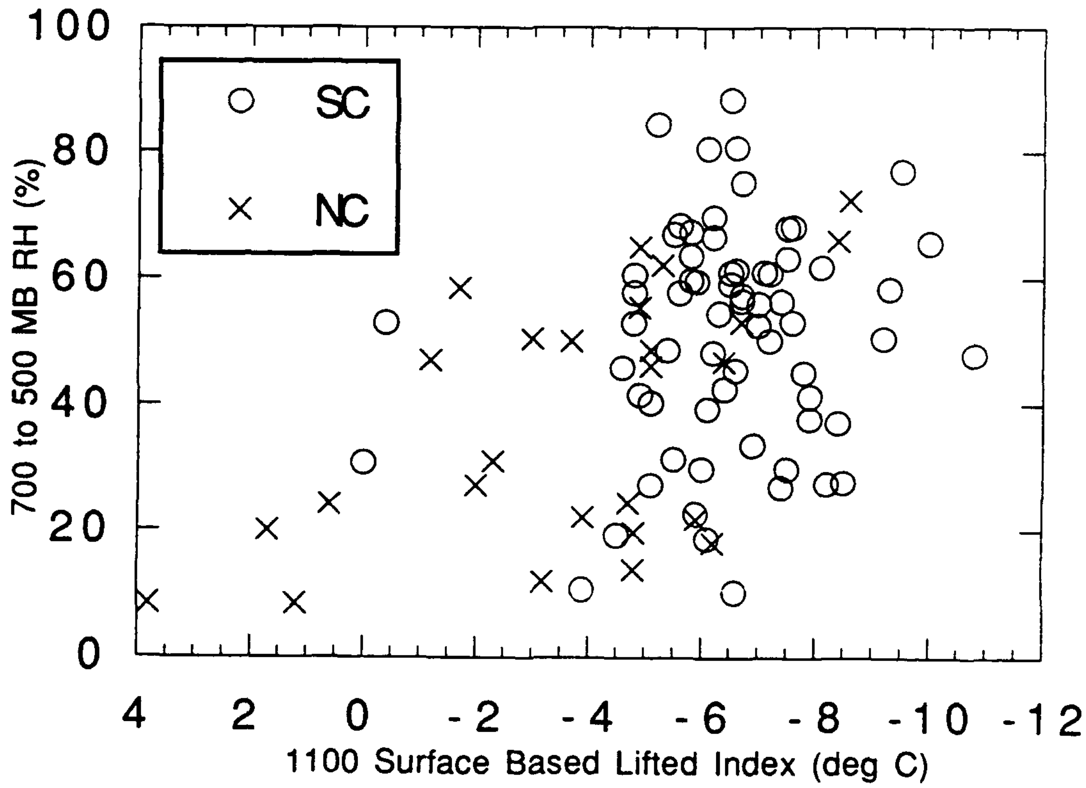



Fig. 20. Scatter plot of 1100 Surface based Lifted Index (SLI) versus 700 to 500 mb mean relative humidity for strong and no convection categories.

no convection days tend to have more stable surface conditions and drier mid-level conditions than strongly convective days.

Although the SLI and mid-tropospheric moisture content are reasonably good predictors of convective activity in the Florida panhandle, Fig. 20 indicates that there are many days on which the unexpected occurred. That is, some mornings that appear very moist and unstable have no significant convection. Conversely, several mornings that appear very stable do have significant convective activity later in the day. The 1200 UTC and subsequent 0000 UTC soundings were compared on these anomalous days. There were no significant differences in moisture or predominant flow patterns between the morning and evening soundings during these cases. Therefore other factors, such as major differences in convergence patterns, must have caused the convective activity to be different from that suggested by the sounding data.

Several methods were used to statistically describe the relative success of the various stability parameters. Generally speaking, the greater the spread between mean values of an index for each convection category, the better the predictive ability of that index. However, the test statistic defined by McClave and Dietrich (1988) helped determine which index demonstrated the most significant differences between forecast categories. The following equation defines the test statistic ($z_{ab}$):

$$z_{ab} = (\overline{X}_a - \overline{X}_b)\left(\frac{S_a^2}{n_a} + \frac{S_b^2}{n_b}\right)^{-\frac{1}{2}}, \quad (3)$$

where $\overline{X}_a$ and $\overline{X}_b$ are mean values for categories a and b of the stability index being compared, $n_a$ and $n_b$ represent the number of events in each category,

and $s_a$ and $s_b$ are standard deviations of the index within the particular categories.

Results of the test statistic comparisons are given in Table 1. The table compares the relative usefulness of the SSI, LI, KI, 0900 EDT SLI, and 1100 EDT SLI. On this table, $z_{sw}$ compares the mean stability indices between the strong and weak convective categories, $z_{wn}$ compares the weak and no convection categories, and $z_{sn}$ the strong and no convection categories. The larger the absolute value of the number in Table 1, the greater the significance of the difference between categories. For example, an absolute value greater than 1.7 means there is at least a 95% chance that the differences between mean values do not occur by random chance. An absolute value greater than 2.4 means that there is at least a 99% chance that the differences are statistically significant.

The results (Table 1) show the SLI to be the overall best stability index in differentiating between categories of convection. The SLI gives better results at 1100 EDT than at 0900 EDT. The LI is slightly less useful. The KI differentiates between weak and no convection days and between strong and no convection days. However, it has no value in differentiating between the strong and weak convection days. The SSI has much less success in differentiating between any category.

Although the test statistics help show which stability indices may be more useful in forecasting convection, they do not quantify the accuracy of a convective forecast based on a particular index. Before attempting to evaluate the predictive success of the various stability indices, I had to decide what to do with the middle (weak convection) category. The stability distributions (Figs. 13 -

Table 1. Test statistic comparisons between Strong and Weak convection category (SW), Weak and No convection category (WN), and Strong and No convection category (SN). Comparisons are made for the given stability indices. The numbers in bold italics are significant at the 99% level.

| | $z_{SW}$ | $z_{WN}$ | $z_{SN}$ |
|---|---|---|---|
| SSI | -0.05 | -1.47 | -1.80 |
| LI | -1.89 | -1.34 | ***-2.89*** |
| KI | -0.11 | ***2.71*** | ***3.18*** |
| SLI (0900L) | ***-3.48*** | -1.54 | ***-3.96*** |
| SLI (1100L) | ***-2.66*** | -2.03 | ***-4.43*** |

17) showed that the median value of the weak convection category fell between median values of the strong and no convection categories. However, there was no clear demarkation between each of the separate categories. Rather than throwing out the weak convection cases to allow a direct comparison between the strong and no convection categories, I added the weak convection cases to one of the other categories. Since, the weak convection category represented days having only a few small convective cells, these days would easily satisfy what the National Weather Service calls "less than 20%" coverage of convective precipitation. Therefore, I decided to group the weak convection days with the no convection days.

The Critical Success Index (CSI) is a commonly used method for statistically evaluating the success of a forecast. The CSI combines the attributes of both the Probability of Detection (POD) and the False Alarm Rate (FAR). These statistical methods are described in Schaefer (1990) and in Watson et al. (1991). The CSI can be calculated using 2 x 2 contingency tables. The CSI, however, is not always the best method for evaluating forecast effectiveness. For example the CSI equation does not give any credit for a successful negative forecast. In other words, the success of forecasting a less than 20% probability of convection, and verifying that forecast, is not included. Schaefer (1990) stated that the CSI is a biased score that depends on the frequency of the event being forecast. He also noted that the CSI overestimates the skill, with the magnitude of the overestimation increasing as the frequency of the event being forecast increases. Because of these inadequacies of the CSI, I chose to evaluate the success of stability index-derived convective forecasts using the True Skill Statistic (TSS) as discussed by Watson et al. (1991) and Doswell and Flueck (1989).

The TSS was used because, unlike the CSI, it utilizes all the information in the contingency table. Another advantage of the TSS is that it compares observed skill to perfect skill. It has a fixed range from -1 to +1, where TSS = 1 indicates perfect skill. Equation 4 gives the formula for the TSS:

$$TSS = POD - POFD, \tag{4}$$

where POD means the Probability Of Detection and POFD is the Probability Of False Detection. The following equations define the POD and POFD:

$$POD = FSCOSC \;/\; TOSC \tag{5}$$

$$POFD = FSCNO \;/\; TONC. \tag{6}$$

"Forecast Strong Convection, Observed Strong Convection" (FSCOSC) represents the total number of correct strong convection forecasts while the "Total Observed Strong Convection" (TOSC) represents the total number of strong convection days in the data set. On the other hand, the "Forecast Strong Convection Not Observed" (FSCNO), is the total number of forecasts of strong convection that did not verify, and "Total Observed No Convection" (TONC) is the total number of days in the data set that had weak or no convection.

The TSS calculations were made after determining the stability values that would be the ideal forecast threshold for each index. These thresholds were determined using the stability index distributions shown in Tables 2 - 6. The thresholds were then used to set up contingency tables. The TSS was calculated for each contingency table of each index . The thresholds then were

Table 2. Distribution of Showalter Stability Index (SSI) for each category.

| | Index Values (deg C) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Conv. Cat. | ≥4.5 | 4 | 3.5 | 3 | 2.5 | 2 | 1.5 | 1 | 0.5 | 0 | -0.5 | -1 | -1.5 | -2 | -2.5 | ≤-3 |
| SC | 5 | 0 | 2 | 1 | 3 | 6 | 4 | 10 | 8 | 5 | 6 | 3 | 2 | 3 | 2 | 6 |
| WC | 1 | 1 | 1 | 1 | 4 | 2 | 0 | 1 | 1 | 1 | 2 | 2 | 4 | 0 | 1 | 1 |
| NC | 5 | 2 | 0 | 1 | 1 | 2 | 3 | 1 | 2 | 1 | 2 | 2 | 2 | 1 | 0 | 1 |

Table 3. Distribution of K index (KI) for each category.

| | Index Values (deg C) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Conv. Cat. | ≤21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | ≥36 |
| SC | 6 | 0 | 2 | 0 | 2 | 6 | 2 | 4 | 5 | 8 | 5 | 3 | 9 | 8 | 3 | 3 |
| WC | 1 | 1 | 0 | 0 | 0 | 1 | 3 | 4 | 0 | 1 | 3 | 2 | 1 | 1 | 3 | 2 |
| NC | 9 | 1 | 2 | 1 | 0 | 0 | 3 | 0 | 2 | 2 | 4 | 1 | 0 | 0 | 0 | 1 |

Table 4. Distribution of Lifted Index (LI) for each category.

| | Index Values (deg C) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Conv. Cat. | ≥-0.5 | -1 | -1.5 | -2 | -2.5 | -3 | -3.5 | -4 | -4.5 | -5 | -5.5 | -6 | -6.5 | -7 | -7.5 | ≤-8 |
| SC | 4 | 2 | 2 | 3 | 6 | 7 | 6 | 11 | 8 | 7 | 3 | 3 | 2 | 0 | 1 | 1 |
| WC | 3 | 1 | 3 | 1 | 5 | 0 | 0 | 4 | 1 | 3 | 1 | 0 | 1 | 0 | 0 | 0 |
| NC | 6 | 0 | 1 | 5 | 3 | 1 | 4 | 1 | 1 | 2 | 1 | 0 | 1 | 0 | 0 | 0 |

Table 5. Distribution of Surface based Lifted Index (SLI) at 0900 EDT for each category.

| | Index Values (deg C) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Conv. Cat. | ≥-1 | -1.5 | -2 | -2.5 | -3 | -3.5 | -4 | -4.5 | -5 | -5.5 | -6 | -6.5 | -7 | -7.5 | -8 | ≤-8.5 |
| SC | 1 | 1 | 0 | 0 | 1 | 1 | 6 | 7 | 6 | 8 | 6 | 7 | 7 | 6 | 2 | 7 |
| WC | 1 | 1 | 1 | 1 | 1 | 0 | 3 | 4 | 4 | 1 | 2 | 2 | 2 | 0 | 0 | 0 |
| NC | 4 | 2 | 0 | 2 | 0 | 4 | 2 | 3 | 3 | 1 | 2 | 0 | 2 | 1 | 0 | 0 |

Table 6. Distribution of Surface based Lifted Index (SLI) at 1100 EDT for each category.

| | Index Values (deg C) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Conv. Cat. | ≥-1 | -1.5 | -2 | -2.5 | -3 | -3.5 | -4 | -4.5 | -5 | -5.5 | -6 | -6.5 | -7 | -7.5 | -8 | ≤-8.5 |
| SC | 2 | 0 | 0 | 0 | 0 | 1 | 0 | 6 | 4 | 9 | 9 | 11 | 7 | 8 | 3 | 6 |
| WC | 1 | 0 | 0 | 1 | 2 | 0 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 0 | 1 |
| NC | 5 | 1 | 2 | 0 | 2 | 2 | 0 | 5 | 3 | 1 | 2 | 1 | 0 | 0 | 1 | 1 |

varied and the TSS values recalculated. The threshold with the greatest TSS for each index was determined to have the best forecast skill. Tables 7 - 11 show TSS results for these optimum thresholds or cutoff points. The ranked results of the TSS calculations are shown in Table 12.

The best forecast results (Table 12) are produced by the SLI at 1100 EDT. The -5.5 $^{o}$C cutoff for the 1100 EDT SLI produces a TSS of 0.45. This -5.5 $^{o}$C threshold means that strong convective activity would be forecast at SLI values less than or equal to -5.5 $^{o}$C. At SLI values greater than -5.5 $^{o}$C, the forecast would call for no significant convective activity in the region. This TSS was computed using the data shown in Table 11. Using the equation for the POD (5) and the data from Table 11, the POD = 53 / 66 = 0.80. For the POFD, Table 11 and (6) yield POFD = 17 / 49 = 0.35. Now, (4) is used to give TSS = 0.80 - 0.35 = 0.45 for the 1100 EDT SLI. The SLI computed *several hours* earlier, at 0900 EDT, is slightly less successful, with a TSS of 0.38 at its cutoff point (also -5.5 $^{o}$C). The conventional LI is the best of the stability indices that are based solely on the morning sounding. The LI has a TSS of 0.31 using the cutoff of -3.0 $^{o}$C. TSS values for the KI and SSI are 0.19 and 0.18, respectively. They are much less successful than the other indices, only slightly better than a blind, "always strong convection" forecast. A forecast of strong convection each day would give a TSS of 0.0.

The forecast skill of the various stability indices was examined in a final way. The frequency distributions in Tables 2 - 6 were used to specify three forecast categories: unstable, stable, and a middle range. The middle range represents stability values having little predictive ability. The threshold values

Table 7. Contingency Table for Showalter Stability Index (SSI). Strong Convection (SC) forecast for SSI $\leq$ 1.5 deg C. FSCOSC stands for forecast strong convection and observed strong convection.; SUMOSC is for the sum of the observed strong convection days, and so on.

| Predicted | Observed SC | Observed WC / NC | Total |
|---|---|---|---|
| SC ( $\leq$1.5) | 49 | 28 | 77 |
| WC / NC (>1.5) | 17 | 21 | 38 |
| Total | 66 | 49 | 115 |

POD = FSCOSC / TOSC = 0.83
POFD = FSCNO / TONC = 0.65
TSS = POD - POFD = 0.18

Table 8. Contingency Table for K Index. Strong Convection forecast for KI $\geq$ 26 deg C.

| Predicted | Observed SC | Observed WC / NC | Total |
|---|---|---|---|
| SC ( $\geq$ 26) | 56 | 34 | 90 |
| WC / NC (<26) | 10 | 15 | 25 |
| Total | 66 | 49 | 115 |

POD = FSCOSC / TOSC = 0.88
POFD = FSCNO / TONC = 0.69
TSS = POD - POFD = 0.19

Table 9. Contingency Table for Lifted Index (LI). Strong Convection forecast for LI $\leq$ - 3.0 deg C.

| Predicted | Observed SC | Observed WC / NC | Total |
|---|---|---|---|
| SC ( $\leq$ -3.0) | 49 | 21 | 70 |
| WC / NC (>-3.0) | 17 | 28 | 45 |
| Total | 66 | 49 | 115 |

POD = FSCOSC / TOSC = 0.74
POFD = FSCNO / TONC = 0.43
TSS = POD - POFD = 0.31

Table 10. Contingency Table for Surface based Lifted Index (SLI) using 0900 EDT Tallahassee surface temperatures and dew points. Strong Convection (SC) forecast for SLI ≤ -5.5 deg C.

| | Observed | | |
|---|---|---|---|
| Predicted | SC | WC / NC | Total |
| SC ( ≤ -5.5) | 43 | 13 | 56 |
| WC / NC (> -5.5) | 23 | 36 | 59 |
| Total | 66 | 49 | 115 |

POD = FSCOY / TOSC = 0.65
POFD = FSCNO / TONC = 0.27
TSS = POD - POFD = 0.38

Table 11. Contingency Table for Surface based Lifted Index (SLI) using 1100 EDT Tallahassee surface temperatures and dew points. Strong Convection forecast for SLI ≤ - 5.5 deg C.

| | Observed | | |
|---|---|---|---|
| Predicted | SC | WC / NC | Total |
| SC ( ≤ -5.5) | 53 | 17 | 70 |
| WC / NC (>-5.5) | 13 | 32 | 45 |
| Total | 66 | 49 | 115 |

POD = FSCOSC / TOSC = 0.80
POFD = FSCNO / TONC = 0.35
TSS = POD - POFD = 0.45

Table 12. Rankings of degree of success of the True Skill Statistic (TSS).

| Stability Index | Best Forecast Cutoff (Deg C) | TSS |
|---|---|---|
| 1100 EDT SLI | -5.5 | 0.45 |
| 0900 EDT SLI | -5.5 | 0.38 |
| LI | -3.0 | 0.31 |
| KI | 26.0 | 0.19 |
| SSI | 1.5 | 0.18 |
| Control "Always Strong Convection" | -- | 0.00 |

defining it were selected so that approximately 50% of the days within the specified stability range actually had strong convection. Using SLI at 1100 EDT as an example (Table 6), 23 days have values between 4.5 and 5.5 $^{o}$C at 1200 UTC. Of these, 10 days (or 43.5%) experience strong convection later in the day. This value is entered in Table 13. Percentage frequencies of strong convection occurring at stable and unstable ranges of each index are also shown in Table 13.

The results again show the 1100 EDT SLI to be the superior predictor (Table 13). At the more unstable values (SLI $\leq$ -5.5 $^{o}$C), 75.7% of the days have strong convection. These results are significantly better than the control "always strong convection" forecast of 57.4%. At stable values of SLI (greater than -4.5 $^{o}$C), there is only a 13.6% probability of strong convection. Therefore, the SLI is also useful in forecasting the nonoccurrence of significant convective activity. Table 13 shows that the SLI is much better than the other indices at predicting the nonoccurrence of thunderstorms when index values denoted stable conditions. Results for SLI at 0900 EDT are similar to those at 1100, but the number of cases in the uncertain middle range is greater. It appears that by exclusively using the 1100 EDT SLI, a good forecast for strong convective activity can be made when values are sufficiently large or small. Of course, there is the middle range of values where a successful convective forecast cannot be made. In this middle range, the forecaster needs to rely on other predictive factors.

Continuing with this method of forecast evaluation, the conventional LI is slightly less successful than the SLI (Table 13). The KI and the SSI are even

Table 13. Percentage of occurrence of Strong Convection (SC) on days within given stability index ranges.

| Index | Stable Range | Middle Range | Unstable Range |
|---|---|---|---|
| SSI | (> 2.0) - 39.2 % | ($\leq$ 2.0 and > 1.0) - 58.8% | ($\leq$ 1.0) - 64.3 % |
| KI | (< 25) - 34.8 % | ($\geq$ 25 and < 29) - 56.0% | ($\geq$ 29) - 65.7 % |
| LI | ( > -2.5) - 35.5 % | ($\leq$ -2.5 and > -3.0) - 42.8% | ($\leq$ -3.0) - 70.0 % |
| SLI(0900 EDT) | ( > -3.5) - 19.0 % | ($\leq$ - 4.0 and > -5.5) - 50.0 % | ($\leq$ - 5.5) - 76.8 % |
| SLI(1100 EDT) | ( > -4.5) - 13.6 % | ($\leq$ - 4.5 and > -5.5) - 43.5 % | ($\leq$ - 5.5) - 75.7 % |

less useful. These indices do not help forecast the presence or absence of strong convective activity in the Florida panhandle.

## 4. Conclusions

This study has investigated the pre-convective environments of summer thunderstorms over the Florida panhandle using ground based and remotely sensed data. One kilometer half-hourly GOES satellite imagery centered over the Florida panhandle was recorded on a near daily basis on a high quality video recorder. In addition, upper air data at 1200 UTC were archived for the Florida panhandle. The data were recorded during the summers of 1990 and 1991. A total of 115 days had both usable satellite imagery and upper air data during the research period. Days were classified as "disturbed" or "non-disturbed" using the satellite imagery. The "non-disturbed" days were further categorized as having "strong", "weak", or "no" convection. Mean sounding profiles of various meteorological parameters were constructed for each category of the non-disturbed days. Several different stability indices were also calculated each day to determine which index performed best in north Florida during the summer.

Results show that the best thermodynamic parameters to consider in forecasting convection over north Florida include mid-tropospheric moisture and low level instability. The humidity between 500 and 700 mb correlates best with convective activity. The average relative humidity of this layer on strong convection days is nearly 20% greater than on no convection days.

Low level instability, which is strongly influenced by low level humidity, is also a very important ingredient for convective activity in the Florida panhandle.

The best stability index for predicting convective development was found to be the Surface based Lifted Index (SLI). The SLI allows stability to be computed at a later time than is possible using 1200 UTC upper air soundings. This index also allows stability to be calculated at locations that are not necessarily upper air sites. The 1100 EDT SLI was more accurate than the 0900 EDT SLI in predicting the afternoon convection. The SLI index at 1100 EDT still provides several hours lead time in forecasting the onset of most strong convective activity. The conventional Lifted Index was found to have limited value in forecasting north Florida convection. The K Index and the Showalter Stability Index have almost no predictive value.

Several factors relating to wind direction are important to convective development in the Florida panhandle. The no convection category has a strong tendency for northerly wind components at all levels. The weak and strong convection categories are more likely to have southerly wind components. This implies that the moisture brought in by southerly winds has a stronger influence on convective development than the increased low level convergence caused by northerly winds colliding with the advancing sea breeze.

The u-component of the wind was also shown to be related to convective development in the Florida panhandle. At 850 mb and below, the strong convective days tended to have a more westerly component. The weak and no convection categories had a more easterly low level component. Low level easterly flow apparently causes a suppression of convective activity in the Florida panhandle in many instances.

The factors mentioned above are all useful in predicting convective development in north Florida. However, convective development on individual

days does not always follow the predicted forecast. Factors not studied in this project also have a significant influence on daily convective activity. For example, low level convergence has frequently been shown to be a major influence on convective development (e.g., Ulanski and Garstang (1977), Cooper et al. (1982), and Watson and Blanchard (1984)). Convergence at the lower levels provides the lift necessary to begin the convection process in a moist, unstable environment. The high resolution satellite imagery used in this research project can infer areas of convergence, but only after convective clouds have formed. Doppler radar technology will give more useful information about convergence because areas of convergence will be detected even before the first convective cells are visible on satellite imagery (Eilts et al. 1991). Also, days with suppressed low level convergence will be detected. The new Doppler technology will give forecasters increased lead time in predicting the occurrence or non occurrence of convective activity. Doppler technology will also pinpoint the specific areas where convective activity is likely. The forecaster of the future will be able to combine information from the latest Doppler radar signatures with his knowledge of the stability and moisture situation for a given day to provide increasingly accurate and site specific predictions of thunderstorm activity.

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## BIOGRAPHICAL SKETCH

David G. Biggar was born August 1, 1963 in Rockford, Illinois. He graduated from Washington Community High School in Washington, Illinois in 1981. In the fall of 1981 he began college at the Florida State University. He received a B.S. in Meteorology in 1985 with minors in Mathematics and Aerospace Studies. After graduation he was commissioned as a Second Lieutenant in the United States Air Force. He completed weather officer assignments for two years each at Homestead AFB, FL and at Spangdahlem AB, Germany. He was promoted to the rank of Captain in May of 1989. In the fall of 1989 he was sponsored by the Air Force to return to FSU to pursue a M.S. in Meteorology. This thesis marks the completion of that goal.